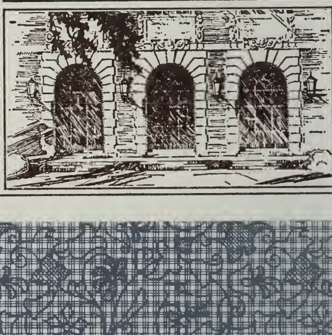
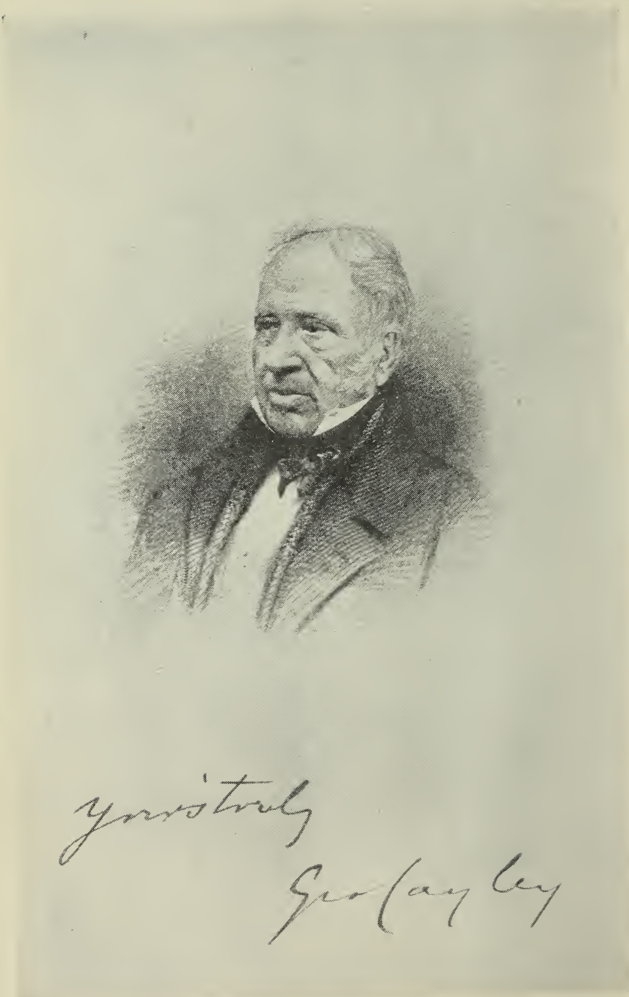


Aerial Navigation


Yours truly
Geo Cayley

THE
AERONAUTICAL CLASSICS

EDITED

FOR THE COUNCIL OF
THE AËRONAUTICAL SOCIETY
OF GREAT BRITAIN

BY

Thomas O'Brian John Henry

T. O'B. HUBBARD AND J. H. LEDEBOER, B.A.

Illustrated with Portraits, Plates, and Diagrams

PRINTED AND PUBLISHED BY
THE AËRONAUTICAL SOCIETY OF GREAT BRITAIN,
11, ADAM STREET, ADELPHI, LONDON, W.C.

1910-11.

(Second impression of this title page, 1915).

"We imitate also Flights of Birds; We have some Degrees of Flying in the Air."

New Atlantis—Francis Bacon

THE AERONAUTICAL CLASSICS

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ADDENDA TO BIBLIOGRAPHY

"**The Art of Flying,**" by THOMAS WALKER

Add :—

Reprinted (1st *Ed.*)	. . . .	1814, *New York*
Reprinted (,,)	. . . .	1816, *New York*

"**The Aerial Ship,**" by FRANCESCO LANA

Add :—

1679. *London*	. .	*Philos. Coll. English Translation by R. Hooke of 6th chap. of "Prodromo."*
1807. *Glasgow*	. .	*Five curious and interesting Papers, &c. Reprint of R. Hooke's Translation of "Prodromo."*

First Published . . .	1809–10	*Nicholson's Jour.*
Reprinted . . .	1876	*Ann. Rep. Aër. Soc.*
Reprinted . . .	1895	*Aer. Ann. (U.S.A.)*
Reprinted . . .	1910	*Aer. Classics*

Edited for the Council of the Aëronautical Society of Great Britain

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BIOGRAPHICAL NOTICE

Sir George Cayley, the 6th baronet of his line, was born at Brompton, Yorkshire, on December 27th, 1773, and married, on July 9th, 1795, Anne Eleanor Shultz by whom he had a considerable family. From his early youth he showed a pronounced leaning towards scientific and philosophical research, and while still in his twenties elaborated a scheme of arterial drainage from systems noted during his "Grand Tour" on the Continent, without which no gentleman's education was then considered complete. This scheme he afterwards applied to the family estates in Yorkshire and Lincolnshire; and 40,000 acres in the neighbourhood of his estate in the former county were also drained by this means. Later he became one of the promoters and first Chairman of the old Polytechnic Institution.

His energies were, however, principally devoted to a subject which had been impressed upon his boyish mind by the Montgolfiers' invention in 1783—aerial navigation. In fact, his whole life may be said to have been devoted to it, as the many papers and communications from his pen in *Nicholson's Journal*, the *Mechanic's Magazine*, the *Philosophical Magazine*, and other scientific periodicals of his day amply testify.

After analysing the mechanical properties of air under chemical and physical action, he proceeded to investigate the power necessary for aerial locomotion, and his knowledge of steam engines led him to point out the fallacy of hopes of any success in this direction in the absence of a given power within a given weight. This led to his invention of the air-engine; while he also seems to have clearly foreseen the gas engine and to have had some idea of electricity as the necessary motor. Indeed he invented an arrangement for applying electric power to machinery, though it does not seem to have been put to any important use. His optical invention may also be mentioned here, being an instrument for testing the purity of water by the abstraction of light, which was used very successfully in investigating the Thames waters.

In aeronautical science he was far ahead of his contemporaries. Had his suggestions been adopted and money been forthcoming for the purpose, a dirigible balloon might have hovered over the field of Waterloo and brought news of Blucher's progress to the anxious Duke. In 1810 he had publicly stated that he could at once construct a balloon "that should carry its passengers at 20 miles an hour"; and judging from the knowledge

displayed in his writings it is quite possible to believe it.

In the year of Queen Victoria's coronation he endeavoured to establish an Aeronautical Society, but without success, for ballooning was in bad odour in those days, and generally regarded as the exclusive property of mountebanks and showmen at country fairs.

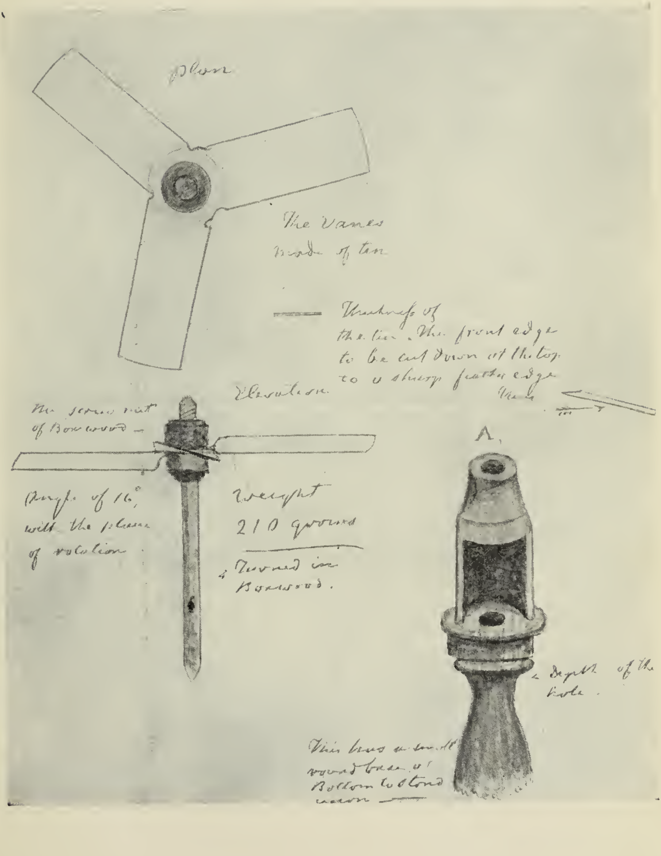
Sir George was a prominent Whig, being Chairman of the Whig Club in York, and it was perhaps with some idea of bringing the subject of aeronautics before Parliament that, when already an old man of seventy, he stood for Scarborough and was returned in the Parliament of 1852. There is no record, however, of his introduction of aeronautics to the House, and, at the end of the ministry two years later, he retired to his country estates on the plea of old age, to resume his cherished hobbies in peace, amusing himself with curious inventions such as artificial hands and strange mechanical contrivances.

The same year, 1854, he sent to M. Dupuis Delcourt, then secretary of the Société Aérostatique et Méteorologique de France, the following description of an improved Chinese top :

> Mr. Cooper of the London University, so far as I know, was the first person who improved upon the clumsy structure of the toy called the Chinese top, & I saw his, in company with Professor Wheatson, mounting say 20 or 25 feet. I made one at Brompton, & sent it to a very ingenious mechanic & engineer, Mr. Coulson of Redcar in this county, who made me one of which this (the accompanying sketch) is an exact copy. It is the best I have ever seen, & will mount upward of 90 feet into the air.

It is scarcely necessary to describe this toy as these rough drawings sufficiently explain the structure & dimensions of each part. It is spun like the common humming top with a strong small cord coiled round the stem when within a suitable handle, as A. The lower end of the stem is pointed & enters half an inch into the lower hole in the handle, so as not to allow the top part to touch the top of the handle.

In 1857, on December 15, Sir George Cayley died, full of years and honour, at the advanced age of 84. He was the Father of British Aeronautics.


Plan
The Vanes made of tin
Thickness of the tin. The front edge to be cut down at the top to a sharp feather edge
Elevation
The screw nut of Boxwood —
A.
Angle of 16° with the plane of rotation.
Weight 210 grains
Turned in Boxwood.
Depth of the hole.
This was a small round base at Bottom to stand upon —

Aerial Navigation

SINCE the days of Bishop Wilkins the scheme of flying by artificial wings has been much ridiculed, and indeed the idea of attaching wings to the arms of a man is ridiculous enough, as the pectoral muscles of a bird occupy more than two-thirds of its whole muscular strength, whereas in man the muscles that could operate upon the wings thus attached would probably not exceed one-tenth of the whole mass. There is no proof that, weight for weight, a man is comparatively weaker than a bird; it is therefore probable, if he can be made to exert his whole strength advantageously upon a light surface similarly proportioned to his weight, as that of the wing to the bird, that he would

fly like a bird. The flight of a strong man by great muscular exertion, though a curious and interesting circumstance, inasmuch as it will probably be the first means of ascertaining this power and supplying the basis whereon to improve it, would be of little use. I feel perfectly confident, however, that this noble art will soon be brought home to man's general convenience, and that we shall be able to transport ourselves and families, and their goods and chattels, more securely by air than by water, and with a velocity of from 20 to 100 miles per hour. To produce this effect it is only necessary to have a first mover, which will generate more power in a given time, in proportion to its weight, than the animal system of muscles.

The consumption of coal in a Boulton & Watt's steam engine is only about $5\frac{1}{2}$ lbs. per hour for the power of one horse. The heat produced by the combustion of this portion of inflammable matter is the sole cause of the power generated, but it is applied through the intervention of a weight of water expanded into steam, and a still greater weight of cold water to condense it again. The engine itself likewise must be massive enough to resist the whole external pressure of the atmosphere, and therefore is not applicable to the purpose proposed. Steam engines have lately been made to operate by expansion only, and these might be constructed so as to be light enough for this purpose, provided the usual plan of a large boiler be given up and the principle of injecting a proper charge of water into a mass of tubes, forming the cavity for the fire, be adopted in lieu of it. The strength of vessels to resist internal pressure being inversely as their diameters, very slight metallic tubes

would be abundantly strong, whereas a large boiler must be of great substance to resist a strong pressure. The following estimate will show the probable weight of such an engine with its charge for one hour :—

	lbs.
The engine itself	90 to 100
Weight of inflamed cinders in a cavity presenting about 4 ft. surface of tube	25
Supply of coal for one hour . .	6
Water for ditto., allowing steam of one atmosphere to be $\frac{1}{1800}$ the specific gravity of water ...	32
	163

I do not propose this statement in any other light than as a rude approximation to truth, for as the steam is operating under the disadvantage of atmospheric pressure it must be raised to a higher temperature than in Messrs. Boulton & Watt's engine, and this will require more fuel; but if it take twice as much still the engine would be sufficiently light, for it would be exerting a force equal to raising 550 lbs. one foot high per second, which is equivalent to the labour of six men, whereas the whole weight does not much exceed that of a man.

It may seem superfluous to enquire further relative to a first mover for aerial navigation, but lightness is of so much value in this instance that it is proper to notice the probability that exists of using the expansion of air, by the sudden combustion of inflammable powders or fluids, with great advantage. The French have lately

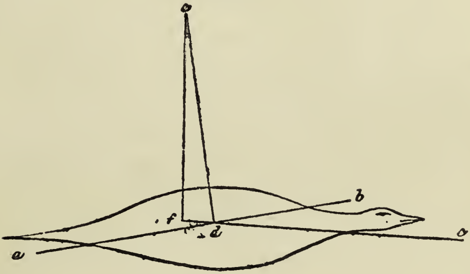
shown the great power produced by igniting inflammable powders in close vessels, and several years ago an engine was made to work in this country in a similar manner by inflammation of spirit of tar. I am not acquainted with the name of the person who invented this engine, but from some minutes with which I was favoured by Mr. William Chapman, of Newcastle, I find that 30 drops of oil of tar raised 8 cwt. to the height of 22 ins.; hence 1 horse-power would consume from 10 to 12 lbs. per hour, and the engine itself need not exceed 50 lbs. weight. I am informed by Mr. Chapman that this engine was exhibited in a working state to Mr. Rennie, Mr. Cartwright, and several other gentlemen capable of appreciating its powers, but that it was given up in consequence of the expense attending its consumption, being about eight times greater than that of a steam engine of the same power. Probably a much cheaper engine of this sort might be produced by a gas-light apparatus and by firing the inflammable air generated with a due portion of common air under a piston.* Upon some of these principles it is perfectly clear that force can be obtained by a much lighter apparatus than the muscles of animals or birds, and therefore in such proportion may aerial vehicles be loaded with inactive matter. Even the expansion steam engine, doing the work of six men and only weighing equal to one, will as readily raise five men into the air as one man can elevate himself by his own exertions, but by increasing the magnitude of the engine 10, 50,

* This prophecy was fulfilled nearly 56 years later in the Lenoir gas engine.—[EDS.]

or 500 men may be equally well conveyed, and convenience alone, regulated by the strength and size of materials, will point out the limit for the size of vessels in aërial navigation.

Having rendered the accomplishment of this object probable upon the general view of the subject, I shall proceed to point out the principles of the art itself. For the sake of perspicuity I shall, in the first instance, analyse the most simple action of the wing in birds, although it necessarily supposes many previous steps.

Fig. 1.



When large birds, that have a considerable extent of wing compared with their weight, have acquired their full velocity, it may frequently be observed that they extend their wings, and without waving them continue to skim for some time in a horizontal path. Fig. 1 represents a bird in this act. Let *ab* be a section of the plane of both wings opposing the horizontal current of air (created by its own motion), which may be represented by the line *cd*, and is the measure of the velocity of the bird. The angle *bdc* can be increased at the will of the bird, and to preserve a perfectly horizontal

path, without the wing being waved, must continually be increased in a complete ratio (useless at present to enter into) till the motion is stopped altogether; but at one given time the position of the wings may be truly represented by the angle *bdc*. Draw *de* perpendicular to the plane of the wings, produce the line *cd* as far as required, and from the point *e*, assumed at pleasure in the line *de*, let fall *ef* perpendicular to *df*; then *de* will represent the whole force of the air under the wing, which being resolved into the two forces *ef* and *fd* the former represents the force that sustains the weight of the bird, the latter the retarding force by which the velocity of the motion producing the current *cd* will be continually diminished; *ef* is always a known quantity, being equal to the weight of the bird, and hence *fd* is also known as it will always bear the same proportion to the weight of the bird as the sine of the angle *bdc* bears to its cosine, the angles *def* and *bdc* being equal. In addition to the retarding force thus received is the direct resistance which the bulk of the bird opposes to the current. This is a matter to be entered into separately from the principles now under consideration, and for the present may be wholly neglected under the supposition of its being balanced by a force precisely equal and opposite to itself.

Before it is possible to apply this basis of the principle of flying in birds to the purpose of aerial navigation it will be necessary to encumber it with a few practical observations.

The whole problem is confined within these limits, viz.—To make a surface support a given weight by the application of power to the resistance of air. Magnitude

is the first question respecting the surface. Many experiments have been made upon the direct resistance of air by Mr. Robins, Mr. Rouse, Mr. Edgeworth, Mr. Smeaton, and others. The result of Mr. Smeaton's experiments and observations was that a surface of a square foot met with a resistance of 1 lb. when it travelled perpendicularly to itself through air at a velocity of 21 ft. per second. I have tried many experiments upon a large scale to ascertain this point. The instrument was similar to that used by Mr. Robins, but the surface used was larger, being an exact square foot, moving round upon an arm about 5 ft. long, and turned by weights over a pulley. The time was measured by a stop-watch, and the distance travelled over in each experiment was 600 ft. I shall only give the results of many carefully-repeated experiments, which are, that a velocity of 11.538 ft. per second generated a resistance of 4 oz., and that a velocity of 17.16 ft. per second gave 8 oz. resistance. This delicate instrument would have been strained by the additional weight necessary to have tried the velocity generating a pressure of 1 lb. per square foot; but if the resistance be taken to vary as the square of velocity, the former will give the velocity necessary for this purpose at 23.1 ft., the latter 24.28 ft. per second. I shall therefore take 23.6 ft. as somewhat approaching the truth.

Having ascertained this point, had our tables of angular resistance been complete, the size of the surface necessary for any given weight would easily have been determined. Theory, which gives the resistance of a surface opposed to the same current in different angles to be as the square of the sine of the angle of incidence,

is of no use in this case, as it appears, from the experiments of the French Academy, that in acute angles the resistance varies much more nearly in the direct ratio of the sines than as the squares of the sines of the angle of incidence. The flight of birds will prove to an attentive observer that, with a concave wing apparently parallel to the horizontal path of the bird, the same support and, of course, resistance is obtained; and hence I am inclined to suspect that under extremely acute angles, with concave surfaces, the resistance is nearly similar in them all. I conceive the operation may be of a different nature from what takes place in larger angles, and may partake more of the principle of pressure exhibited in the instrument known by the name of the hydrostatic paradox. A slender filament of the current is constantly received under the anterior edge of the surface and directed upward into the cavity by the filament above it, being obliged to mount along the convexity of the surface, having created a slight vacuity immediately behind the point of separation. The fluid accumulated thus within the cavity has to make its escape at the posterior edge of the surface where it is directed considerably downward, and therefore has to overcome and displace a portion of the direct current passing with its full velocity immediately below it; hence whatever elasticity this effort requires operates upon the whole concavity of the surface, excepting a small portion of the anterior edge. This may or may not be the true theory, but it appears to me to be the most probable account of a phenomenon which the flight of birds proves to exist.

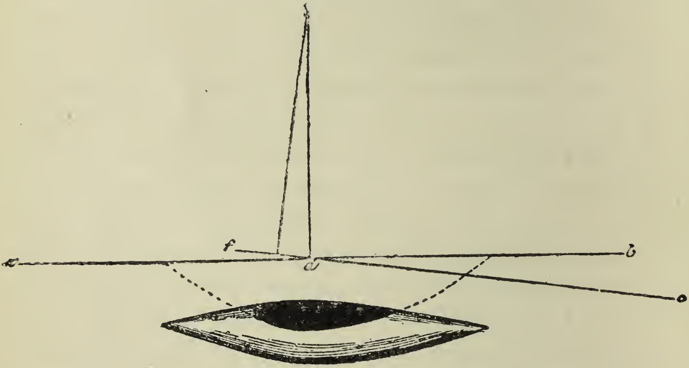
Six degrees was the most acute angle, the resistance

of which was determined by the valuable experiments of the French Academy, and it gave $\frac{4}{10}$ of the resistance which the same surface would have received from the same current when perpendicular to itself. Hence, then, a superficial foot, forming an angle of six degrees with the horizon, would, if carried forward horizontally (as a bird in the act of skimming) with a velocity of 23.6 ft. per second, receive a pressure of $\frac{4}{10}$ of a pound perpendicular to itself; and if we allow the resistance to increase as the square of the velocity at 27.3 ft. per second, it would receive a pressure of 1 lb. I have weighed and measured the surface of a great many birds, but at present shall select the common rook, because its surface and weight are as nearly as possible in the ratio of a superficial foot to a pound. The flight of this bird, during any part of which they can skim at pleasure, is (from an average of many observations) about 34.5 ft. per second. The concavity of the wing may account for the greater resistance here received than the experiments upon plane surfaces would indicate. I am convinced that the angle made use of in the crow's wing is much more acute than 6 degrees; but in the observations that will be grounded upon these data I may safely state that every foot of such curved surface, as will be used in aerial navigation, will receive a resistance of 1 lb. perpendicular to itself when carried through the air in an angle of 6 degrees with the line of its path at a velocity of about 34 to 35 ft. per second.

Let *ab*, Fig. 2, represent such a surface or sail made of thin cloth, and containing about 200 square feet (if of a square form the side will be a little more than 14 ft.), and the whole of a firm texture. Let the weight

of the man and the machine be 200 lbs. Then if a current of wind blew in the direction *cd* with a velocity of 35 ft. per second, at the same time that a cord, represented by *cd*, would sustain a tension of 21 lbs., the machine would be suspended in the air, or at least be within a few ounces of it (falling short of such support only in the ratio of the sine of the angle of 94 degrees compared with the radius, to balance which defect suppose a little ballast to be thrown out), for the

Fig. 2.



line *de* represents a force of 200 lbs., which, as before being resolved into *df* and *fe*, the former will represent the resistance in the direction of the current, and the latter that which sustains the weight of the machine. It is perfectly indifferent whether the wind blow against the plane or the plane be driven with an equal velocity against the air. Hence if this machine were pulled along by a cord, *cd*, with a tension of about 21 lbs., at a velocity of 35 ft. per second, it would be suspended in

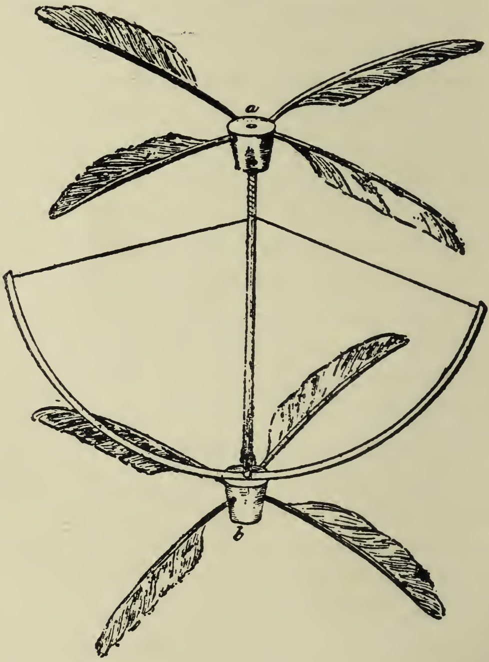
a horizontal path; and if, in lieu of this cord, any other propelling power were generated in this direction, with a like intensity, a similar effect would be produced. If therefore the waft of surfaces advantageously moved by any force generated within the machine took place to the extent required, aerial navigation would be accomplished. As the acuteness of the angle between the plane and current increases, the propelling power required is less and less. The principle is similar to that of the inclined plane, in which, theoretically, 1 lb. may be made to sustain all but an infinite quantity, for in this case if the magnitude of the surfaces be increased *ad infinitum*, the angle with the current may be diminished, and consequently the propelling force in the same ratio. In practice the extra resistance of the car and other parts of the machine, which consume a considerable portion of power, will regulate the limits to which this principle, which is the true basis of aerial navigation, can be carried; and the perfect ease with which some birds are suspended in long horizontal flights, without one waft of their wings, encourages the idea that a slight power only is required.

I have myself made a large machine on this principle, large enough for aerial navigation, but which I have not had an opportunity to try the effect of, excepting as to its proper balance and security. It was beautiful to see this noble white bird sail majestically from the top of a hill to any given point of the plane below it with perfect steadiness and safety, according to the set of its rudder, merely by its own weight descending in an angle of about 8 degrees with the horizon.

As it may be amusing to some of my readers to see a

machine rise in the air by mechanical means, the following is a description of one of which anyone can construct at the expense of ten minutes' labour :—*a* and *b*, Fig. 3, are two corks, into each of which are inserted

Fig. 3.



four wing feathers, from any bird, so as to be slightly inclined like the sails of a windmill, but in opposite directions in each set. A round shaft is fixed in the cork *a*, which ends in a sharp point. At the upper part of the cork *b* is fixed a whalebone bow, having a

small pivot hole in its centre to receive the point of the shaft. The bow is then to be strung equally on each side to the upper portion of the shaft, and the little machine is completed. Wind up the string by turning the flyers different ways, so that the spring of the bow may unwind them with their anterior edges ascending. Then place the cork with the bow attached to it upon a table, and with the finger on the upper cork press strong enough to prevent the string from unwinding, and taking it away suddenly, the machine will rise to the ceiling. This was the first experiment I made upon this subject in the year 1796.

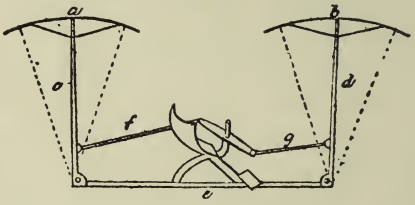
If in lieu of these small feathers large planes, containing together 200 square feet, were similarly placed, or in any other more convenient position, and were turned by a man or first mover of adequate power, a similar effect would be the consequence, and for the mere purpose of ascent this is perhaps the best apparatus; but speed is the great object of this invention, and this requires a different structure.

In lieu of applying the continued action of the inclined plane, by means of the rotative motion of flyers, the same principle may be made use of by the alternative motion of surfaces backward and forward, as in the following manner :—

Let *a* and *b*, Fig. 4, be two surfaces or parachutes supported upon the long shafts *c* and *d*, which are fixed to the ends of the connecting beam *e* by hinges. At *e* let there be a convenient seat for the aeronaut, and before him a cross-bar turning upon a pivot in the centre, which, being connected with the shafts of the parachute by the rods *f* and *g*, will enable him to work

them alternately backwards and forwards, as represented by the dotted lines. If the upright shaft be elastic or have a hinge to give way a little, near their tops, the weight and resistance of the parachutes will incline them so as to make a small angle with the direction of their motion, and hence the machine rises. A slight heeling of the parachute towards one side, or an alteration in the position of the weight, may enable the aeronaut to steer such an apparatus tolerably well; but many better constructions may be formed for com-

Fig. 4.



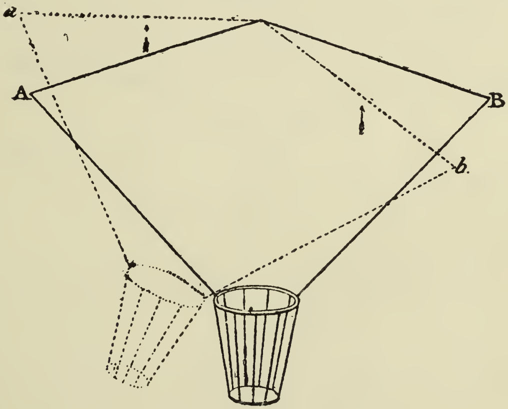
bining the requisites of speed, convenience, and steerage.*

Having described the general principle of support in aerial navigation, I shall proceed to show how this principle must be applied so as to be steady and manageable. Several persons have ventured to descend from balloons in a parachute which exactly resembles a large umbrella, with a light car suspended by cords underneath it. It is very remarkable that the only

* Cayley here refers to the apparatus of Degen, a Viennese watchmaker, who was erroneously reported to have raised himself by its aid into the air. The Lamplough machine exhibited at the Aero Show, Olympia, London, March, 1909, employed exactly these principles.—[EDS.]

machines of this sort which have been constructed are nearly of the worst possible form for producing a steady descent—the purpose for which they are intended. To render this subject more familiar let us recollect that in a boat swimming upon water its stability or stiffness depends, in general terms, upon the weight and distance from the centre of the section elevated above the water by any given heel of the boat on one side; and on the

Fig. 5.

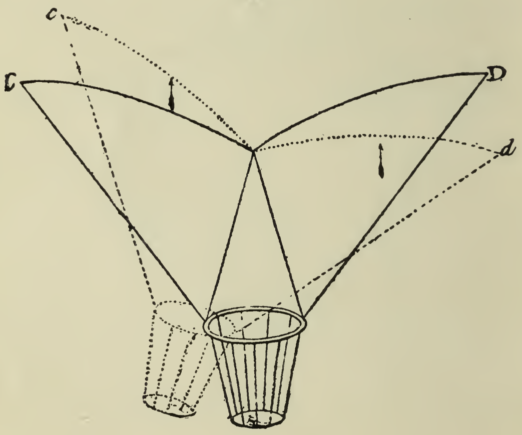


bulk and its distance from the centre, which is immersed below the water on the other side, the combined endeavour of the one to fall and the other to swim produces the desired effect in a well-constructed boat. The centre of gravity of the boat being more or less below the centre of suspension is an additional cause of its stability.

Let us now examine the effect of a parachute represented by *ab*, Fig. 5. When it has heeled into the

position represented by the dotted lines, *a* is become perpendicular to the current created by the descent, and therefore resists with its greatest power; whereas the side *b* is become more oblique, and of course its resistance is much diminished. Hence, so far as this form of the sail or plane is regarded, it operates directly in opposition to the principle of stability, for the side that is required to fall resists much more in its new

Fig. 6.

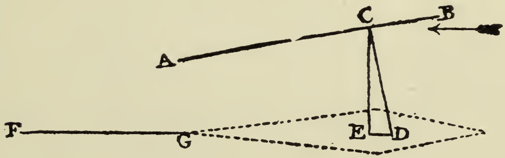


position, and that which is required to rise resists much less; therefore complete inversion would be the consequence if it were not for the weight being suspended so very much below the surface, which, counteracting this tendency, converts the effort into a violent oscillation.

On the contrary, let the surface be applied in the inverted position as represented at *cd*, Fig. 6, and suppose it to be heeled to the same angle as before repre-

sented by the dotted lines *cd*. Here the exact inverse of the former instance takes place, for that side which is required to rise has gained resistance by its new position, and that which is required to sink has lost it; so that as much power operates to restore the equilibrium in this case as tended to destroy it in the other, the operation very much resembling what takes place in the common boat. This angular form, with apex downwards, is the chief basis of stability in aerial navigation; but as the sheet which is to suspend the weight attached to it in its horizontal path through the air must present a slightly concave surface in a small angle with

Fig. 7.



the current, this principle can only be used in the lateral extension of the sheet, and this most effectually prevents any rolling of the machine from side to side. Hence the section of the inverted parachute, Fig. 6, may equally well represent the cross section of a sheet for aerial navigation. The principle of stability in the direction of the path of the machine must be derived from a different source.

Let *ab*, Fig. 7, be a longitudinal section of a sail, and let *c* be its centre of resistance, which experiment shows to be considerably more forward than the centre of the sail. Let *cd* be drawn perpendicular to *ab*, and let the

centre of gravity of the machine be at any point in that line as at *d*; then if it be projected in a horizontal path, with velocity enough to support the weight, the machine will retain its relative position like a bird in the act of skimming, for drawing *ce* perpendicular to the horizon, and *de* parallel to it, the line *ce* will, at some particular moment, represent the supporting power and likewise its opponent, the weight; and the line *de* will represent the retarding power and its equivalent, that portion of the projectile force expended in overcoming it; hence, these various powers being exactly balanced, there is no tendency in the machine but to proceed in its path with its remaining portion of projectile force.

The stability in this position, arising from the centre of gravity being below the point of suspension, is aided by a remarkable circumstance that experiment alone could point out. In very acute angles with the current it appears that the centre of resistance in a sail does not coincide with the centre of its surface, but is considerably in front of it. As the obliquity of the current decreases these centres approach and coincide when the current becomes perpendicular to the sail. Hence any heel of the machine backward or forward removes the centre of support behind or before the point of suspension, and operates to restore the original position by a power equal to the whole weight of the machine, acting upon a lever equal in length to the distance the centre has removed.

To render the machine perfectly steady, and likewise to enable it to ascend and descend in its path, it becomes necessary to add a rudder in a similar position to the tail in the bird. Let *fg* be the section of such a

surface parallel to the current and let it be capable of moving up and down upon *g* as a centre, and of being fixed in any position. The powers of the machine being previously balanced, if the least pressure be exerted by the current either upon the upper or under surface of the rudder, according to the will of the aeronaut, it will cause the machine to rise or fall in its path so long as the propelling force is continued with sufficient energy.

From a variety of experiments upon this subject I find that when the machine is going forward, with a superabundant velocity, or that which would induce it to rise in its path, a very steady horizontal course is effected by a considerable depression of the rudder, which has the advantage of making use of this portion of sail in aiding the support of the weight. When the velocity is becoming less, as in the act of alighting, then the rudder must gradually recede from this position and even become elevated for the purpose of preventing the machine from sinking too much in front, owing to the combined effect of the want of projectile force sufficient to sustain the centre of gravity in its usual position, and of the centre of support approaching the centre of the sail.

The elevation and depression of the machine are not the only purposes for which the rudder is designed. This appendage must be furnished with a vertical sail and be capable of turning from side to side in addition to its other movements, which effects the complete steerage of the vessel.

All these principles upon which the support, steadiness, elevation, depression, and steerage of vessels for

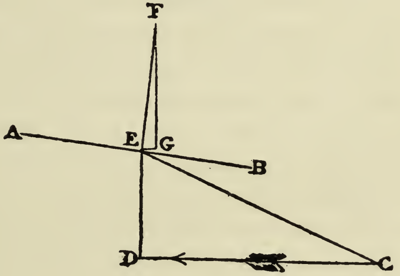
aerial navigation depend have been abundantly verified by experiments both upon a large and small scale. I made a machine having a surface of 300 square feet, which was accidentally broken before there was an opportunity of trying the effect of the propelling apparatus, but its steerage and steadiness were perfectly proved, and it would sail obliquely downwards in any direction according to the set of the rudder. Its weight was 56 lbs., and it was loaded with 84 lbs., thus making a total of 140 lbs., about 2 square feet to 1 lb. Even in this state, when any person ran forward in it with his full speed, taking advantage of a gentle breeze in front, it would bear upward so strongly as scarcely to allow him to touch the ground, and would frequently lift him up and convey him several yards together.

The best mode of producing the propelling power is the only thing that remains yet untried towards the completion of the invention. I am preparing to resume my experiments upon this subject, and state the following observations in the hope that others may be induced to give their attention towards expediting the attainment of this art.

The act of flying is continually exhibited to our view, and the principles upon which it is effected are the same as those before stated. If an attentive observer examines the waft of a wing he will perceive that about one-third part towards the extreme point is turned obliquely backward, this being the only portion that has velocity enough to overtake the current passing so rapidly beneath it when in this unfavourable position. Hence this is the only portion that gives any propelling force.

To make this more intelligible let *ab*, Fig. 8, be a section of this part of the wing. Let *cd* represent the velocity of the bird's path or the current, and *ed* that of the wing in its waft; then *ce* will represent the magnitude and direction of the compound or actual current striking the under surface of the wing. Suppose *ef*, perpendicular to *ab*, to represent the whole pressure; *eg*, being parallel to the horizon, will represent the propelling force, and *gf*, perpendicular to it, the supporting power. A bird is supported as effectually

Fig 8.



during the return as during the beat of its wing. This is chiefly effected by receiving the resistance of the current under that portion of the wing next the body, where its receding motion is so slow as to be of scarcely any effect. The extreme portion of the wing, owing to its velocity, receives a pressure downward and obliquely forward, which forms part of the propelling force, and at the same time by forcing the hinder part of the middle portion of the wing downward, so increases its angle with the current as to enable it still to receive nearly its usual pressure from beneath.

As the common rook has its surface and weight in the ratio of a square foot to the lb., it may be considered as a standard for calculation of this sort; and I shall therefore state, from the average of many careful observations, the movements of that bird. Its velocity, represented by *cd*, Fig. 8, is 34.5 ft. per second. It moves its wing up and down once in flying over a space of 12.9 ft. Hence, as the centre of resistance of the extreme portion of the wing moves over a space of 0.75 of a foot each beat or return, its velocity is about 4 ft. per second, represented by the line *ed*. As the wing certainly overtakes the current it must be inclined from it at an angle something less than 7°, for at this angle it would scarcely be able to keep parallel with it unless the waft downward was performed with more velocity than the return, which may be, and probably is, the case, though these movements appear of equal duration.

The propelling power represented by *eg* under these circumstances cannot be equal to $\frac{1}{8}$ part of the supporting power *gf* exerted upon this portion of the wing, yet this, together with the aid from the return stroke, has to overcome all the retarding power of the surface and the direct resistance occasioned by the bulk of the bird.

It has been before suggested, and I believe upon good grounds, that very acute angles vary little in the degree of resistance they make under a similar velocity of current. Hence it is probable that this propelling part of the wing receives little more than its common proportion of resistance during the waft downward. If it be taken at one-third of the whole surface, and one-eighth of this be allowed as the propelling power, it will only amount to $\frac{1}{24}$ of the weight of the bird, and even

this is exerted only half the duration of the flight. The power gained in the return of the wing must be added to render this statement correct, and it is difficult to estimate this; yet the following statement proves that a greater degree of propelling force is obtained upon the whole than the foregoing observations will justify.

Suppose the largest circle that can be described in the breast of a crow to be 12 in. in area : such a surface moving at a velocity of 34.5 ft. per second would meet a resistance of 0.216 of a lb., which, reduced by the proportion of the resistance of a sphere to its great circle (given by Mr. Robins as 1 to 2.27), leaves a resistance of 0.095 of a lb. had the breast been hemispherical. It is probable, however, that the curve made use of by Nature to avoid resistance being so exquisitely adapted to its purpose will reduce this quantity to one half less than the resistance of the sphere, which would ultimately leave 0.0475 of a lb. as somewhat approaching the true resistance. Unless, therefore, the return of the wing gives a greater degree of propelling force than the beat, which is improbable, no such resistance of the body could be sustained. Hence, though the eye cannot perceive any distinction between the velocities of the beat and return of the wing, it probably exists, and experiment alone can determine the proper ratio between them.

From these observations we may, however, be justified in the remark that the act of flying requires less exertion than from the appearance is supposed.

Not having sufficient data to ascertain the exact degree of propelling power exerted by birds in the act

of flying, it is uncertain what degree of energy may be required in this respect for vessels for aerial navigation; yet when we consider the many hundred miles of continued flight exerted by birds of passage, the idea of its being only a small effort is greatly corroborated. To apply the power of the first mover to the greatest advantage in producing this effect is a very material point. The mode universally adopted by Nature is the oblique waft of the wing. We have only to choose between the direct beat overtaking the velocity of the current, like the oar of a boat, or one applied like the wing, in some assigned degree of obliquity to it. Suppose 35 ft. per second to be the velocity of an aerial vehicle, the oar must be moved with this speed previous to its being able to receive any resistance; then if it be only required to obtain a pressure of $\frac{1}{10}$ of a lb. upon each square foot it must exceed the velocity of the current 7.5 ft. per second. Hence its whole velocity must be 42.5 ft. per second. Should the same surface be wafted downward like a wing, with the hinder edge inclined upward in an angle of about $50^\circ\ 40'$ to the current, it will overtake it at a velocity of 3.5 ft. per second; and as a slight unknown angle of resistance generates a lb. pressure per square foot at this velocity, probably a waft of little more than 4 ft. per second would produce this effect, one-tenth part of which would be the propelling power. The advantage in favour of this mode of application, compared with the former, is rather more than ten to one.

In continuing the general principles of aerial navigation, for the practice of the art, many mechanical difficulties present themselves which require a consider-

able course of skilfully-applied experiments before they can be overcome; but, to a certain extent, the air has already been made navigable, and no one who has seen the steadiness with which weights, to the amount of ten stone (including four stone, the weight of the machine), hover in the air, can doubt of the ultimate accomplishment of this object.

The first impediment I shall take notice of is the great power that must be exerted previous to the machine's acquiring that velocity which gives support upon the principle of the inclined plane, together with the total want of all support during the return of any surface used like a wing. Many birds, and particularly water fowl, run and flap their wings for several yards before they gain support from the air. The swift (*hirundo apus*, *Lin.*) is not able to elevate itself from level ground. The inconvenience under consideration arises from very different causes in these two instances. The supportive surface of most swimming birds does not exceed the ratio of four-tenths of a square foot to every lb. of their weight. The swift, though it scarcely weighs an ounce, measures 18 in. in extent of wing. The want of surface in the one case and the inconvenient length of wing in the other oblige these birds to aid the commencement of their flight by other expedients, yet they can both fly with great power when they have acquired this full velocity.

A second difficulty in aërial navigation arises from the great extent of lever which is constantly operating against the first mover in consequence of the distance of the centre of support in large surfaces, if applied in the manner of wings.

A third and general obstacle is the mechanical skill required to unite great extension of surface with strength and lightness of structure, at the same time having a firm and steady movement in its working parts, without exposing unnecessary obstacles to the resistance of the air. The first of these obstacles that have been enumerated operates much more powerfully against aerial navigation upon a large scale than against birds, because the small extent of their wings obliges them to employ a very rapid succession of strokes in order to acquire that velocity which will give support, and during the small interval of the return of the wing this weight is still rising, as in a leap, by the impulse of one stroke till it is again aided by another. The large surfaces that aerial navigation will probably require, though necessarily moved with the same velocity, will have a proportionately longer duration both of the beat and return of the wing, and hence a greater descent will take place during the latter action than can be overcome by the former.

There appear to be several ways of obviating this difficulty. There may be two surfaces, each capable of sustaining weight, and placed one above the other, having such a construction as to work up and down in opposition when they are moved, so that one is always ready to descend the moment the other ceases. These surfaces may be so made, by a valve-like structure, as to give no opposition in rising up, and only to resist in descent. The action may be considered either oblique, as in rotative flyers, alternately so, without any up-and-down waft as in the engine I have described at Fig. 12, a number of small wings in lieu of large ones, upon the

principle of the flight of birds, with small intervals of time between each waft, and, lastly, by making use of light wheels to preserve the propelling power, both of the beat and the return of the wings, till it accumulates sufficiently to elevate the machine upon the principle of those birds which run themselves up. This action might be aided by making chcice of a descending ground like the swift.

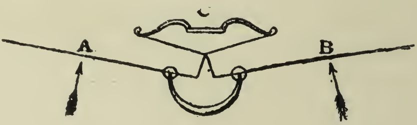
With regard to another part of the first obstacle I have mentioned, viz.,—the absolute quantity of power demanded being so much greater at first than when the full velocity has been acquired,—it may be observed that, in the case of human muscular strength being made use of, a man can exert, for a few seconds, a surprising degree of force. He can run upstairs for instance with a velocity of from 6 to 8 ft., perpendicular height, per second, without any dangerous effort. Here the muscles of his legs only are in action, but, for the sake of making a moderate statement, suppose that with the activity of his arms and body, in addition to that of his legs, he is equal to rising his weight 8 ft. per second; if in this case he weighs 11 stone, or 154 lbs., he will be exerting, for the time, an energy equal to more than the ordinary force of two of Messrs. Boulton & Watt's steam horses, and certainly more than twelve men can bestow upon their constant labour. If expansive first movers be made use of they may be so constructed as to be capable of doing more than their constant work, or their power may be made to accumulate for a few moments by the formation of a vacuum or the condensation of air, so that these expedients may restore at one time, in addition to the

working of the engine, that which they had previously absorbed from it.

With regard to the second obstacle in the way of aerial navigation, viz.,—the length of leverage to which large wing-like surfaces are exposed,—it may be observed that being a constant and invariable quality, arising from the degree of support such surfaces give, estimated at their centres of resistance, it may be balanced by an elastic agent that is so placed as to oppose it.

Let *a* and *b*, Fig. 9, be two wings of an aerial vehicle in the act of skimming, then half the weight of the

Fig. 9.



vessel is supported from the centre of resistance of each wing, as represented by the arrows under them. If the shorter ends of these levers be connected by cords to the string of a bow *c*, of sufficient power to balance the weight of the machine at the points *a* and *b*, then the moving power will be left at full liberty to produce the waft necessary to bend up the hinder edge of the wing and gain the propelling power. A bow is not in fact an equable spring, but may be made so by using a spiral fusee. I have made use of it in this place merely as the most simple mode of stating the principles I wished to exhibit. Should a counter-balancing spring of this kind be adopted in the practice of aerial naviga-

tion, a small well-polished cylinder, furnished with what may be termed a bag-piston (upon the principle made use of by Nature in preventing the return of blood to the breast, when it has been driven into the aorta by the intervention of the semilunar valves), would, by a vacuum being excited each stroke of the wing, produce the desired effect, with scarcely any loss of friction. I have made use of several of these pistons, and have no scruple in asserting that, for all blowing engines, where friction is an evil, and being very nearly air-tight is sufficient, there is no piston at all comparable with them. The most irregular cylinder with a piston of this kind will act with surprising effect. To give an instance: a cylinder of sheet-tin, 8 in. long and $3\frac{1}{2}$ in. in diameter, required 4 lbs. to force the piston down in 15 minutes, and in other trials became perfectly tight in some positions, and would proceed no farther. The friction, when the cylinder was open at both ends, did not exceed half-an-ounce. These elastic agents may likewise be useful in gradually stopping the momentum of large surfaces when used in any alternate motion, and in thus restoring it during their return.

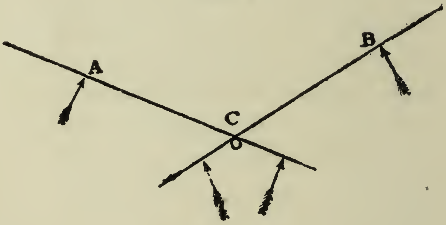
Another principle that may be applied to obviate this leverage of a wing is that of using such a construction as will make the supporting power of the air counterbalance itself. It has been before observed that only about one-third of the wing in birds is applied in producing the propelling power, the remainder, not having velocity sufficient for this purpose, is employed in giving support both in the beat and return of the wing.

Let *a* and *b*, Fig. 10, be two wings continued beyond the pole or hinge upon which they turn at *c*. If the

extreme parts at *a* and *b* be long and narrow they may be balanced, when in the act of skimming, by a broad extension of less length on their opposite side, this broad extension, like the lower part of the wing, will always give nearly the same support, and the propelling part of the surface will be at liberty to act unincumbered by the leverage of its supporting power. This plan may be modified many different ways, but my intention, as in the former case, is still the principle in its simplest form.

A third principle upon which the leverage of a sur-

Fig. 10.

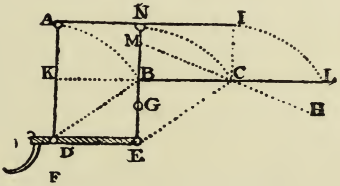


face may be prevented is by giving it a motion parallel to itself, either directly up and down or obliquely so. The surface *ai*, Fig. 11, may be moved perpendicularly by the shaft which supports it down to the position *kc*, or if it be supported upon two shafts, with hinges at *d* and *e*, it may be moved obliquely parallel to itself into the position *bl*.

A fourth principle upon which the leverage may be greatly avoided, when only one hinge is used, is by placing it considerably below the plane of the wing, as at the point *d*, Fig. 11, in respect to the surface *a*. It

may be observed in the heron, which is a weak bird with an extended surface, that its wings curve downward considerably from the hinge to the tip; hence the extreme portion which receives the chief part of the stroke is applied obliquely to the current it creates, and thus evades, in a similar degree, the leverage of that portion of the supportive power which is connected with the propelling power. These birds seldom carry their waft much below the level of the hinge of the wing, where this principle, so far as respects the supporting power, would vanish.

Fig. 11.



By making use of two shafts of unequal length the two last-mentioned principles may be blended to any required extent. Suppose one hinge to be at *f* and the other at *g*, Fig. 11, then the surface, at the extent of its beat, would be in the position of the line *hm*. If the surface *ai*, Fig. 11, be supported only upon one shaft *ne*, be capable of being forced in some degree from its rectangular position in respect to the shaft, and be concave instead of flat, as here represented, then the waft may be used alternately backward and forward, according to the principles of the machine I have described at Fig. 12. This construction combines the principles of

counterpoising the supporting power of one part of the surface by that of an opposite part when the machine is in the act of skimming, and likewise the advantages of the low hinge, with the principle of leaving little or no interval without support.

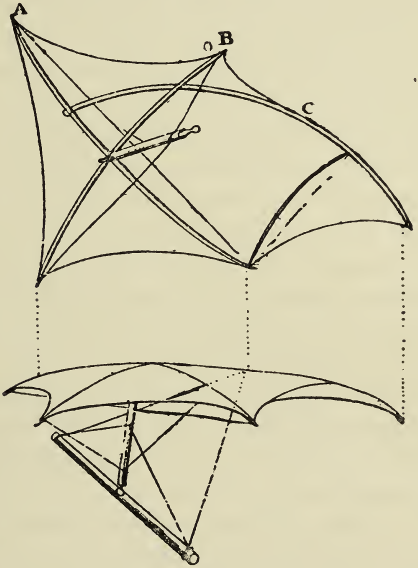
A fifth mode of avoiding leverage is by using the continued action of oblique horizontal flyers, or an alternate action of the same kind, with surfaces so constructed as to accommodate their position to such alternate motion, the hinge or joint being in these cases vertical. In the construction of large vessels for aerial navigation a considerable portion of fixed sail will probably be used, and no more surface will be allotted towards gaining the propelling power than what is barely necessary, with the extreme temporary exertion of the first mover, to elevate the machine and commence the flight. In this case the leverage of the fixed surface is done away.

The general difficulties of structure in aerial vehicles (arising from the extension, lightness, and strength required in them, together with great firmness in the working parts, and at the same time such an arrangement as exposes no unnecessary obstacles to the current) I cannot better explain than by describing a wing which has been constructed with a view to overcome them.

Fig. 12 represents the shape of the cloth, with a perspective view of the poles upon which it is stretched with perfect tightness. Upon the point where the rods *a* and *b* intersect is erected an oval shaft, embracing the two cross poles by a slender iron fork, for the purpose of preserving their strength uninjured by boring. To

this shaft are braced the ends of the pole *b*, so as to give this pole any required degree of curvature. The pole *a* is strung like a common bow to the same curve as the pole *b*, and is only connected with the upright shaft by what may be called a check brace, which will

Figs. 12 and 13.



allow the hinder end of this pole to heel back to a certain extent, but not the fore end. The short brace producing this effect is shown in Fig. 12. Fig. 13 exhibits the fellow wing to that represented in Fig. 12 erected upon a beam, to which it is braced so as to convert the whole length of it into a hinge. The four

braces coming from the ends of this beam are shown; two of them terminate near the top of the centre of the other shaft, the others are inserted into the point *c*, Fig. 12, of the tending rod. A slight bow, not more than three-eighths of an inch thick, properly curved by its string and inserted between the hinder end of the pole *a* and the curved pole *c*, completes the wing.

This fabric contained 54 square feet and weighed only 11 lbs. Although both these wings together did not compose more than half the surface necessary for the support of a man in the air, yet during their waft they lifted the weight of 9 stone. The hinder edge, as is evident from the construction, being capable of giving way to the resistance of the air, any degree of obliquity, for the purpose of a propelling power, may be used.

I am more particular in describing this wing because it exemplifies almost all the principles that can be resorted to in the construction of surfaces for aerial navigation. Diagonal bracing is the great principle for producing strength without accumulating weight, and if performed by thin wires looped at their ends, so as to receive several laps of cordage, produces but a trifling resistance in the air and keeps tight in all weather. When bracings are well applied they make the poles to which they are attached bear endwise. The hollow form of the quill in birds is a very admirable structure for lightness combined with strength where external bracings cannot be had, a tube being the best application of matter to resist as a lever; but the principle of bracing is so effectual that if properly applied it will abundantly make up for the clumsiness of human invention in other respects; and should we com-

bine both these principles, and give diagonal bracing to the tubular bamboo cane, surfaces might be constructed with a greater degree of strength and lightness than any made use of in the wings of birds.

The surface of a heron's wing is in the ratio of 7 square feet to a lb. Hence, according to this proportion of wing of 54 square feet, it would weigh about $7\frac{3}{4}$ lbs. On the contrary, the wings of water fowl are so much heavier that a surface of 54 square feet, according to their structure, will weigh $18\frac{1}{2}$ lbs. I have, in these instances, quoted nearly the extreme cases amongst British birds; the wing I have described may therefore be considered as nearly of the same weight in proportion to its bulk as that of most birds.

Another principle exhibited in this wing is that of the poles being couched within the cloth so as to avoid resistance. This is accomplished by the convexity of the frame and the excessive lightness of the cloth. The poles are not allowed to form the edge of the wing, excepting at the extreme point of the bow, where it is very thin, and also oblique to the current. The thick part of this pole is purposely conveyed considerably within the edge. In birds a membrane covered with feathers is stretched before the thick part of the bone of the wing, in a similar manner and for the same purpose. The edge of the surface is thus reduced to a thickness of a small cord that is sewn to the cloth, and gives out loops whenever any fastening is required. The upright shaft is the only part that opposes much direct resistance to the current, and this is obviated in a great degree by a flat oval shape having its longest axis parallel to the current.

The joint or hinge of this wing acts with great firmness in consequence of its being supported by bracings to the line of its axis, and at a considerable distance from each other; in fact the bracings form the hinge.

The means of communicating motion to any surfaces must vary so much, according to the general structure of the whole machine, that I shall only observe at present that where human muscular action is employed the movement should be similar to the mode of pulling oars, from which any other required motion may be derived. The foot-board in front enables a man to exert his full force in this position. The wings I have described were wafted in this manner, and when they lifted, with a power of 9 stone, not half of the blow which a man's strength could have given was exerted, in consequence of the velocity required being greater than convenient under the circumstances. Had these wings been intended for elevating the person who worked them, they should have contained from 100 to 150 square feet each, but they were constructed for the purpose of an experiment relative to the propelling power only.

Avoiding direct resistance is the next general principle that it is necessary to discuss. Let it be remembered, as a maxim in the art of aerial navigation, that every lb. of direct resistance that is done away will support 30 lbs. of additional weight without any additional power. The figure of a man seems but ill calculated to pass with ease through the air, yet I hope to prove him to the full as well-made, in this respect, as the crow, which has hitherto been one standard of comparison, paradoxical as it may appear.

The principle that surfaces of similar bodies increase only as the squares of their homologous lines, while their weights, or rather solid contents, increase as the cubes of those lines, furnishes the solution. This principle is unanimously in favour of large bodies. The largest circle that can be described in a crow's breast is about 12 square inches in area. If a man exposes a direct bulk of 6 square feet the ratio of their surfaces will be as 1 to 72, but the ratio of their weight is as 1 to 110, which is $1\frac{1}{2}$ to 1 in favour of the man, provided he were within a case as well-constructed for evading resistance as the body of the crow; but even supposing him to be exposed in his natural cylindric shape, in the foreshortened posture of sitting to work his oars, he will probably receive less resistance than the crow.

It is of great importance to this art to ascertain the real solid of least resistance when the length or breadth is limited. Sir Isaac Newton's beautiful theorem upon this subject is of no practical use, as it supposes each particle of the fluid, after having struck the solid, to have free egress; making the angles of incidence and reflection equal. Particles of light seem to possess this power, and the theory will be true in that case; but in the air the action is more like an accumulation of particles, rushing up against each other in consequence of those in contact with the body being retarded.

The importance of this subject is not less than the difficulties it presents. It affects the present interests of society in its relation to the time occupied in the voyages of ships. It will still have more effect when aerial navigation, now in its cradle, is brought home

to the uses of man. I shall state a few crude hints upon this point, to which my subject has so unavoidably led, and on which I am so much interested, and shall be glad if in so doing I may excite the attention of those who are competent to an undertaking greatly beyond my grasp.

Perhaps some approach toward ascertaining the actual solid of least resistance may be derived from treating the subject in a manner something similar to the following:—Admit that such a solid is already attained, the length and width being necessarily taken at pleasure. Conceive the current intercepted or disturbed by the largest circle that can be drawn within the given spindle, to be divided into concentric tubular laminæ of equal thickness. At whatever distance from this great circle the apex of the spindle commences, on all sides of this point the central lamina will be reflected in diverging pencils (or rather an expanding ring) making their angles of incidence and reflection equal. After this reflection they rush against the second lamina and displace it. This second lamina contains three times more fluid than the first; consequently each pencil in the first meets three pencils in the second, and their direction after the union will be one-fourth of the angle with respect to the axis which the first reflection created. In this direction these two laminæ proceed till they are themselves reflected, when they (considered as one lamina of large dimensions) rush against the third and fourth, which together contain three times the fluid in the two former laminæ, and thus reduce the direction of the combined mass to one-fourth of the angle between the axis and the line of the second re-

flection. This process is constant, whatever be the angles formed between the surface of the actual solid of least resistance at these points of reflection and the directions of the currents thus reflected.

From this mode of reasoning, which must in some degree resemble what takes place, and which I only propose as a resemblance, it appears that the fluid keeps creeping along the curved surface of such a solid, meeting it in very acute angles. Hence, as the experiments of the French Academy show that the difference of resistance between the direct impulse and that in an angle of six degrees, on the same surface, is only in the ratio of 10 to 4, it is probable that in the slight difference of angles that occur in this instance the resistances may be taken as equal upon every part, without any material deviation from truth. If this reasoning be correct it will reduce the question, so far as utility is concerned, within a strictly abstract mathematical enquiry.

It has been found by experiment that the shape of the hinder part of the spindle is of as much importance as that of the front in diminishing resistance. This arises from the partial vacuity created behind the obstructing body. If there be no solid to fill up this space a deficiency of hydrostatic pressure exists within it, and is transferred to the spindle. This is seen distinctly near the rudder of a ship in full sail, where the water is much below the level of the surrounding sea. The cause here being more evident and uniform in its nature may probably be obviated with better success, inasmuch as this portion of the spindle may not differ essentially from the simple cone. I fear, however, that the whole

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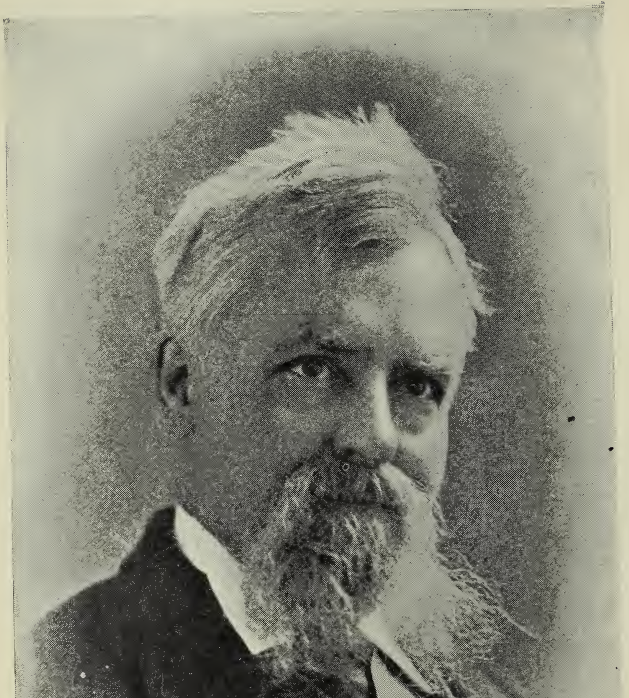
of this subject is of so dark a nature as to be more usefully investigated by experiment than by reasoning, and in the absence of any conclusive evidence from either, the only way that presents itself is to copy Nature.

Aerial Locomotion



Aeronautical Classics—**No. 2**

Aerial Locomotion

BY

F. H. WENHAM

Printed and Published for

THE AËRONAUTICAL SOCIETY OF GREAT BRITAIN,

By King, Sell & Olding, Ltd., 27, Chancery Lane, W.C.

1910

First Published .	1866	1st *Ann. Rep. Aër. Soc.*
Reprinted	1895	*Aer. Ann. (U.S.A.)*
Reprinted	1910	*Aer. Classics*

Edited for the Council of the Aëronautical Society of Great Britain

by

T. O'B. HUBBARD & J. H. LEDEBOER

BIOGRAPHICAL NOTICE

With the death of Wenham there passed away the last of those great figures whose enthusiastic devotion to the cause of artificial flight gave it an impulse, about the middle of the last century, which has never died away. To their pioneer work the present development of the motor-propelled flying machine is directly traceable. The earliest enduring result of their labours was the foundation of the Aëronautical Society, the first and, perhaps, ablest body of men who ever banded themselves together in the cause of aeronautics.

Although it is difficult to trace with perfect accuracy the inception of its foundation, it is clear, at all events that from the very first meeting the Society was swayed by a single predominating figure—that of Wenham.

Francis Herbert Wenham was born in Kensington in 1824. From an early age he gave evidence of possessing

a keen interest in mechanical problems, and, in 1841, he entered a large marine engineering firm at Bristol as a pupil. His first notable independent work was in connection with tubular marine boilers; he designed a high-pressure steam boiler which gave excellent results and was finally built into a small yacht in 1853. With this steamer he visited Egypt in 1858 and steamed up the Nile to the second cataract; on his return to Cairo the steamer was purchased by the reigning Pasha, Mahommed Ali. It was during this expedition that Wenham made the close observations of bird-flight on which he subsequently based his designs.

These observations also formed the basis of his famous treatise, here re-printed, which he read at the first meeting of the Aëronautical Society, held on June 27, 1866, at the Society of Arts under the presidency of the Duke of Argyll. This treatise, which was actually written seven years earlier, immediately after his return from the expedition to Egypt, has since become a classic. It contains, in the direct lucid form wherein Wenham clothed his every utterance, almost every principle, recognised to-day but unknown or unexpressed then, on which modern theory or practice in aviation is founded. There can be but little doubt that Wenham could have constructed a dynamic flying-machine, capable of flight, before ever the Society first met, had he not lacked an efficient prime mover.

Wenham fully recognised this serious obstacle in the road to success, and accordingly, at an even earlier date, turned his attention to devising an efficient light engine; and in so doing he constructed the first light gas engine, forerunner of the internal combustion motor of to-day,

ever made in this country. In parenthesis it may be remarked here that, although Lenoir's motor was designed and built some years before, Wenham's engine was undoubtedly an original, independent, invention; and, at all events, formed the first application of the internal combustion motor to aerial navigation, an application which has since then proved so momentous.

Of no great importance, perhaps, in itself, this fact yet serves to prove the original ability and inventiveness of the man; these qualities were also displayed in other directions, notably in the development of the high-pressure steam boiler, in the invention of the successful hot-air engine that bears his name, in photography, microscopy, and in other branches of optics. He was Vice-President of the Microscopical Society, and for many years was intimately connected, in the quality of scientific adviser, to an eminent firm of opticians in London.

But, in spite of his manifold interests in other subjects, there is little doubt but that, throughout the greater part of his life, aviation occupied a foremost place in his mind. The first experimental work undertaken by the Aëronautical Society, the testing of planes to determine the connection between pressure and velocity, was carried out at Greenwich by Wenham, in conjunction with Mr. John Browning in 1871 and 1872. Of his later writings only his paper read before the first International Aeronautical Congress held in Chicago in 1889 and a contribution to the "Aëronautical Journal" in 1908—a few months before his death—need be mentioned. Wenham died at Folkestone on August 11, 1908.

Lapse of time alone, that has brought about the reali-

sation in practice of the dynamic flying machine, has rendered it possible to estimate his work at its true value. His momentous paper on "Aerial Locomotion" marks a well-defined epoch in the history of practical aeronautics for the following reasons, briefly summarised. It established, in the first place, that the effective sustaining area of an inclined plane propelled through the air is limited to a narrow front portion, thereby rendering extreme *breadth* of surface (transversely to the direction of flight) essential. Secondly, it suggested for the first time that this phenomenon could best be utilised in practice, by superposing the carrying surfaces. Thirdly, it proved that it was unnecessary to carry reduction of weight to the extreme limits advocated until then, and that flight did not require the enormous amount of power usually supposed.

Most noteworthy and illuminating is the fact that these important conclusions were directly derived, by the soundest reasoning, from the simple observation of natural phenomena. In this respect, as in so many others, Wenham owes nothing to any predecessor; his work is original throughout, and bears the deep impress of an independent mind. It is chiefly owing to this very quality that Wenham's work preserves its freshness even until this present day; save for a few unimportant details, it seems almost incredible that more than half-a-century has elapsed since it was written. Of this we may be sure, in years to come, when the early history of aviation has become veiled with the dim twilight of half-forgotten things, the figure of Wenham will stand out clear and strong above the deepening shadows.

Aerial Locomotion

And the Laws by which Heavy Bodies impelled through Air are sustained

THE resistance against a surface of a defined area, passing rapidly through yielding media, may be divided into two opposing forces. One arising from the cohesion of the separated particles; and the other from their weight and inertia, which, according to well-known laws, will require a constant power to set them in motion.

In plastic substances, the first condition, that of cohesion, will give rise to the greatest resistance. In water this has very little retarding effect, but in air, from its extreme fluidity, the cohesive force becomes inappreciable, and all resistances are caused by its

weight alone; therefore, a weight, suspended from a plane surface, descending perpendicularly in air, is limited in its rate of fall by the weight of air that can be set in motion in a given time.

If a weight of 15 lbs. is suspended from a surface of the same number of square feet, the uniform descent will be 1,300 feet per minute, and the force given out and expended on the air, at this rate of fall, will be nearly six horse-power; and, conversely, this same speed and power must be communicated to the surface to keep the weight sustained at a fixed altitude. As the surface is increased, so does the rate of descent and its accompanying power, expended in a given time, decrease. It might, therefore, be inferred that, with a sufficient extent of surface reproduced, or worked up to a higher altitude, a man might by his exertions raise himself for a time, while the surface descends at a less speed.

A man, in raising his own body, can perform 4,250 units of work—that is, this number of pounds raised one foot high per minute—and can raise his own weight—say, 150 lbs.—twenty-two feet per minute. But at this speed the atmospheric resistance is so small that 120,000 square feet would be required to balance his exertions, making no allowance for weight beyond his own body.

We have thus reasons for the failure of the many misdirected attempts that have, from time to time, been made to raise weights perpendicularly in the air by wings or descending surfaces. Though the flight of a bird is maintained by a constant reaction or abutment against an enormous weight of air in comparison

with the weight of its own body, yet, as will be subsequently shown, the support upon that weight is not necessarily commanded by great extent of wing-surface, but by the direction of motion.

One of the first birds in the scale of flying magnitude is the pelican. It is seen in the streams and estuaries of warm climates, fish being its only food. On the Nile, after the inundation, it arrives in flocks of many hundreds together, having migrated from long distances. A specimen shot was found to weigh twenty-one pounds, and measured ten feet across the wings, from end to end. The pelican rises with much difficulty, but, once on the wing, appears to fly with very little exertion, notwithstanding its great weight. Their mode of progress is peculiar and graceful. They fly after a leader, in one single train. As he rises or descends, so his followers do the same in succession, imitating his movements precisely. At a distance, this gives them the appearance of a long undulating ribbon, glistening under the cloudless sun of an oriental sky. During their flight they make about seventy strokes per minute with their wings. This uncouth-looking bird is somewhat whimsical in its habits. Groups of them may be seen far above the earth, at a distance from the river-side, *soaring*, apparently for their own pleasure. With outstretched and motionless wings, they float serenely, high in the atmosphere, for more than an hour together, traversing the same locality in circling movements. With head thrown back, and enormous bills resting on their breasts, they almost seem asleep. A few easy strokes of their wings each minute, as their momentum or velocity diminishes, serves to keep them

sustained at the same level. The effort required is obviously slight, and not confirmatory of the excessive amount of power said to be requisite for maintaining the flight of a bird of this weight and size. The pelican displays no symptom of being endowed with great strength, for when only slightly wounded it is easily captured, not having adequate power for effective resistance, but heavily flapping the huge wings, that should, as some imagine, give a stroke equal in vigour to the kick of a horse.

During a calm evening, flocks of spoonbills take their flight directly up the river's course; as if linked together in unison, and moved by the same impulse, they alter not their relative positions, but at less than fifteen inches above the water's surface, they speed swiftly by with ease and grace inimitable, a living sheet of spotless white. Let one circumstance be remarked, —though they have fleeted past at a rate of near thirty miles an hour, so little do they disturb the element in which they move that not a ripple of the placid bosom of the river, which they almost touch, has marked their track. How wonderfully does their progress contrast with that of creatures who are compelled to drag their slow and weary way against the fluid a thousandfold more dense, flowing in strong and eddying current beneath them.

Our pennant droops listlessly, the wished-for north wind cometh not. According to custom we step on shore, gun in hand. A flock of white herons, or "buffalo-birds," almost within our reach, run a short distance from the pathway as we approach them. Others are seen perched in social groups upon the backs

of the apathetic and mud-begrimed animals whose name they bear. Beyond the ripening dhourra crops which skirt the river-side, the land is covered with immense numbers of blue pigeons, flying to and fro in shoals, and searching for food with restless diligence. The musical whistle from the pinions of the wood-doves sounds cheerily, as they dart past with the speed of an arrow. Ever and anon are seen a covey of the brilliant, many-coloured partridges of the district, whose *long and pointed wings* give them a strength and duration of flight that seems interminable, alighting at distances beyond the possibility of marking them down, as we are accustomed to do with their plumper brethren at home. But still more remarkable is the spectacle which the sky presents. As far as the eye can reach it is dotted with birds of prey of every size and description. Eagles, vultures, kites and hawks, of manifold species, down to the small, swallow-like, insectivorous hawk common in the Delta, which skims the surface of the ground in pursuit of its insect prey. None seem bent on going forward, but all are soaring leisurely round over the same locality, as if the invisible element which supports them were their medium of rest as well as motion. But mark that object sitting in solitary state in the midst of yon plain: what a magnificent eagle! An approach to within eighty yards arouses the king of birds from his apathy. He partly opens his enormous wings, but stirs not yet from his station. On gaining a few feet more he begins to *walk* away, with half-expanded but motionless wings. Now for the chance fire! A charge of No. 3 from 11 bore rattles audibly but ineffectively upon his densely feathered

body; his walk increases to a run, he gathers speed with his slowly-waving wings, and eventually leaves the ground. Rising at a gradual inclination, he mounts aloft and sails majestically away to his place of refuge in the Lybian range, distant at least five miles from where he rose. Some fragments of feathers denote the spot where the shot had struck him. The marks of his claws are traceable in the sandy soil, as, at first with firm and decided digs, he forced his way, but as he lightened his body and increased his speed with the aid of his wings, the imprints of his talons gradually merged into long scratches. The measured distance from the point where these vanished to the place where he had stood proved that with all the stimulus that the shot must have given to his exertions, he had been compelled to run full twenty yards before he could raise himself from the earth.

Again the boat is under way, though the wind is but just sufficient to enable us to stem the current. An immense kite is soaring overhead, scarcely higher than the top of our lateen yard, affording a fine opportunity for contemplating his easy and unlaboured movements. The cook has now thrown overboard some offal. With a solemn swoop the bird descends and seizes it in his talons. How easily he rises again with motionless expanded wings, the mere force and momentum of his *descent* serving to raise him again to more than halfmast high. Observe him next, with lazy flapping wings, and head turned under his body; he is placidly devouring the pendant morsel from his foot, and calmly gliding onwards.

The Nile abounds with large aquatic birds of almost

every variety. During a residence upon its surface for nine months out of the year, immense numbers have been seen to come and go, for the majority of them are migratory. Egypt being merely a narrow strip of territory, passing through one of the most desert parts of the earth, and rendered fertile only by the periodical rise of the waters of the river, it is probable that these birds make it their grand thoroughfare into the rich districts of Central Africa.

On nearing our own shores, steaming against a moderate head-wind, from a station abaft the wheel the movements of some half-dozen gulls are observed, following in the wake of the ship, in patient expectation of any edibles that may be thrown overboard. One that is more familiar than the rest comes so near at times that the winnowing of his wings can be heard; he has just dropped astern, and now comes on again. With the axis of his body exactly at the level of the eyesight, his every movement can be distinctly marked. He approaches to within ten yards, and utters his wild plaintive note, as he turns his head from side to side, and regards us with his jet black eye. But where is the angle or upward rise of his wings, that should compensate for his descending tendency, in a yielding medium like air? The incline cannot be detected, for, to all appearance, his wings are edgewise, or parallel to his line of motion, and he appears to skim along a *solid* support. No smooth-edged rails, or steel-tired wheels, with polished axles revolving in well-oiled brasses, are needed here for the purpose of diminishing friction, for Nature's machinery has surpassed them all. The retarding effects of gravity in the creature

under notice are almost annulled, for he is gliding forward upon a *frictionless* plane. There are various reasons for concluding that the direct flight of many birds is maintained with a much less expenditure of power, for a high speed, than by any mode of progression.

The first subject for consideration is the proportion of surface to weight, and their combined effect in descending perpendicularly through the atmosphere. The datum is here based upon the consideration of *safety*, for it may sometimes be needful for a living being to drop passively, without muscular effort. One square foot of sustaining surface, for every pound of the total weight, will be sufficient for security.

According to Smeaton's table of atmospheric resistances, to produce a force of *one pound* on a square foot, the wind must move against the plane (or, which is the same thing, the plane against the wind), at the rate of twenty-two feet per second, or 1,320 feet per minute, equal to fifteen miles per hour. The resistance of the air will now balance the weight on the descending surface, and, consequently, it cannot exceed that speed. Now, twenty-two feet per second is the velocity acquired at the *end* of a fall of eight feet—a height from which a well-knit man or animal may leap down without much risk of injury. Therefore, if a man with parachute weigh together 143 lbs., spreading the same number of square feet of surface contained in a circle fourteen and a half feet in diameter, he will descend at perhaps an unpleasant velocity, but with safety to life and limb.

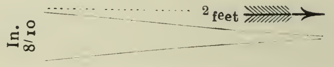
It is a remarkable fact how this proportion of wing-

surface to weight extends throughout a great variety of the flying portion of the animal kingdom, even down to hornets, bees, and other insects. In some instances, however, as in the gallinaceous tribe, including pheasants, this area is somewhat exceeded, but they are known to be very poor flyers. Residing as they do chiefly on the ground, their wings are only required for short distances, or for raising them or easing their descent from their roosting-places in forest trees, the *shortness* of their wings preventing them from taking extended flights. The wing-surface of the common swallow is rather more than in the ratio of *two* square feet per pound, but having also great length of pinion, it is both swift and enduring in its flight. When on a rapid course this bird is in the habit of furling its wings into a narrow compass. The greater extent of surface is probably needful for the continual variations of speed and instant stoppages requisite for obtaining its insect food.

On the other hand, there are some birds, particularly of the duck tribe, whose wing-surface but little exceeds *half* a square foot, or seventy-two inches per pound, yet they may be classed among the strongest and swiftest of flyers. A weight of one pound, suspended from an area of this extent, would acquire a velocity due to a fall of sixteen feet—a height sufficient for the destruction or injury of most animals. But when the plane is urged forward horizontally, in a manner analogous to the wings of a bird during flight, the sustaining power is greatly influenced by *the form and arrangement* of the surface.

In the case of *perpendicular* descent, as a parachute,

the sustaining effect will be much the same, whatever the figure of the outline of the superficies may be, and a circle perhaps affords the best resistance of any. Take, for example, a circle of twenty square feet (as possessed by the pelican) loaded with as many pounds. This, as just stated, will limit the rate of perpendicular descent to 1,320 feet per minute. But instead of a circle sixty-one inches in diameter, if the area is bounded by a parallelogram ten feet long by two feet broad, and whilst at perfect freedom to descend perpendicularly, let a force be applied exactly in a horizontal direction, so as to carry it edgeways, with the long side foremost, at a forward speed of thirty miles per hour—just double that of its passive descent : the rate of fall under these conditions will be decreased most remarkably, probably to less than one fifteenth part, or eighty-eight feet per minute, or one mile per hour.

The annexed line represents transversely the plane two feet wide and ten feet long, moving in the direction of the arrow 

with a forward speed of thirty miles per hour, or 2,640 feet per minute, and descending at eighty-eight feet per minute, the ratio being as one to thirty. Now, the particles of air, caught by the forward edge of the plane, must be carried down eight-tenths of an inch before they leave it. This stratum, ten feet wide and 2,640 long, will weigh not less than 134 lbs.; therefore the weight has continually to be moved downwards, eighty-eight feet per minute, from a state of absolute rest. If the plane, with this weight and an upward rise of eight-tenths of an inch, be carried forward at a rate of thirty miles

per hour, it will be maintained at the same level without descending.

The following illustrations, though referring to the action of surfaces in a denser fluid, are yet exactly analogous to the conditions set forth in air :—

Take a stiff rod of wood, and nail to its end at right angles a thin lath or blade, about two inches wide. Place the rod square across the thwarts of a rowing-boat in motion, letting a foot or more of the blade hang perpendicularly over the side into the water. The direct amount of resistance of the current against the flat side of the blade may thus be felt. Next slide the rod to and fro thwart ship, keeping all square; the resistance will now be found to have increased enormously; indeed, the boat can be entirely stopped by such an appliance. Of course the same experiment may be tried in a running stream.

Another familiar example may be cited in the lee-boards and sliding keels used in vessels of shallow draught, *which act precisely on the same principle as the plane or wing-surface of a bird when moving in air.* These surfaces, though parallel to the line of the vessel's course, enable her to carry a heavy press of sail without giving way under the side pressure, or making lee-way, so great is their resistance against the rapidly passing body of water, which cannot be deflected sideways of a high speed.

The succeeding experiments will serve further to exemplify the action of the same principle. Fix a thin blade, say, one inch wide and one foot long, with its plane exactly midway and at right angles, to the end of a spindle or rod. On thrusting this through a body of

water, or immersing it in a stream running in the direction of the axis of the spindle, the resistance will be simply that caused by the water against the mere superficies of the blade. Next put the spindle and blade in rapid rotation. The retarding effect against direct motion will now be increased near *tenfold*, and is equal to that due *to the entire area of the circle of revolution.* By trying the effect of blades of various widths, it will be found that, for the purpose of effecting the maximum amount of resistance, the more rapidly the spindle revolves the narrower may be the blade. There is a specific ratio between the *width* of the blade and its *velocity*. It is of some importance that this should be precisely defined, not only for its practical utility in determining the best proportion of width to speed in the blades of screw-propellers, but also for a correct demonstration of the principles involved in the subject now under consideration; for it may be remarked that the swiftest-flying birds possess extremely long and *narrow* wings, and the slow, heavy flyers short and wide ones.

In the early days of the screw-propeller, it was thought requisite, in order to obtain the advantage of the utmost extent of surface, that the end-view of the screw should present no opening, but appear as a complete disc. Accordingly, some were constructed with one or two threads, making an entire or two half-revolutions; but this was subsequently found to be a mistake. In the case of the two blades, the length of the screw was shortened, and consequently the width of the blades reduced, with increased effect, till each was brought down to considerably less than *one-sixth*

of the circumference or area of the entire circle; the maximum speed was then obtained. Experiment has also shown that the effective propelling area of the two-bladed screw is tantamount to its entire circle of revolution, and is generally estimated as such.

Many experiments tried by the author, with various forms of screws, applied to a small steam-boat, led to the same conclusion—that the two blades of one-sixth of the circle gave the best result.

All screws reacting on a fluid such as water, must cause it to yield to some extent; this is technically known as "slip," and whatever the ratio or percentage on the speed of the boat may be, it is tantamount to *just so much loss of propelling power*—this being consumed in giving motion to the water instead of the boat.

On starting the engine of the steam-boat referred to, and grasping a mooring-rope at the stern, it was an easy matter to hold it back with one hand, though the engine was equal in power to five horses, and the screw making more than 500 revolutions per minute. The whole force of the steam was absorbed in "slip," or in giving motion to the column of water; but let her go, and allow the screw to find an abutment on a fresh body of water, not having received a gradual motion and with its *inertia undisturbed* when running under full way, the screw worked almost as if in a solid nut, the "slip" amounting to only eleven per cent.

The laws which control the action of inclined surfaces, moving either in straight lines or circles in *air*, are identical, and serve to show the inutility of attempt-

ing to raise a heavy body in the atmosphere by means of rotating vanes or a screw acting vertically; for unless the ratio of surface compared to weight is exceedingly extensive, the whole power will be consumed in "slip," or in giving a downward motion to the column of air. Even if a sufficient force is obtained to keep a body suspended by such means, yet, after the desired altitude is arrived at, *no further ascension* is required; there the apparatus is to remain stationary as to level, and its position on the constantly yielding support can only be maintained at an enormous expenditure of power, for the screw cannot obtain a hold upon a *fresh and unmoved* portion of air in the same manner as it does upon the body of water when propelling the boat at full speed; its action under these conditions is the same as when the boat is held fast, in which case, although the engine is working up to its usual rate, the tractive power is almost annulled.

Some experiments made with a screw, or pair of inclined vanes acting vertically in air, were tried, in the following manner. To an upright post was fixed a frame, containing a bevil wheel and pinion, multiplying in the ratio of three to one. The axle of the wheel was horizontal, and turned by a handle of five-and-a half inches radius. The spindle of the pinion rotated vertically, and carried two driving-pins at the end of a cross-piece, so that the top resembled the three prongs of a trident. The upright shaft of the screw was bored hollow to receive the middle prong, while the two outside ones took a bearing against a driving-bar, at right angles to the lower end of the shaft, the top

of which ended in a long iron pivot, running in a socket fixed in a beam overhead; it could thus rise and fall about two inches with very little friction. The top of the screw-shaft carried a cross-arm, with a blade of equal size at each extremity, the distance from end to end being six feet. The blades could be adjusted at any angle by clamping-screws. Both their edges, and the arms that carried them, were bevilled away to a sharp edge to diminish the effects of atmospheric resistance. A wire stay was taken from the base of each blade to the bottom of the upright shaft, to give rigidity to the arms, and to prevent them from springing upwards. With this apparatus experiments were made with weights attached to the upright screw-shaft, and the blades set at different pitches, or angles of inclination. When the vanes were rotated rapidly, they rose and floated on the air, carrying the weights with them. Much difficulty was experienced in raising a heavy weight by a comparatively small extent of surface, moving at a high velocity; the "slip" in these cases being so great as to absorb all the power employed. The utmost effect obtained in this way was to raise a weight of six pounds on one square foot of sustaining surface, the planes having been set at a coarse pitch. To keep up the rotation, required about half the power a man could exert.

The ratio of weight to sustaining surface was next arranged in the proportion approximating to that of birds. Two of the experiments are here quoted, which gave the most satisfactory result. Weight of wings and shaft, 17½ oz.; area of two wings, 121 inches—equal to 110 square inches per pound. The annexed

figures are given approximately, in order to avoid decimal fractions:—

	No. of revolutions per minute.	Mean sustaining speed Miles per hour.	Feet per minute.	Pitch or angle of rise in one revolution. Inches.	Ratio of pitch to speed.	Slip per cent.
1st Experiment .	210	38	3,360	26	$\frac{1}{8}$th nearly	$12\frac{1}{2}$
2nd do. .	240	44	3,840	15	$\frac{1}{13}$th do.	8

The power required to drive was nearly the same in both experiments—about equal to one-sixteenth part of a horse-power, or the third part of the strength of a man, as estimated by a constant force on the handle of twelve pounds in the first experiment, and ten in the second, the radius of the handle being five-and-a-half inches, and making seventy revolutions per minute in the first case, and eighty in the other.

These experiments are so far satisfactory in showing the small pitch or angle of rise required for sustaining the weight stated, and demonstrating the principle before alluded to, of the slow descent of planes moving horizontally in the atmosphere at high velocities; but the question remains to be answered, concerning the disposal of the excessive power consumed in raising a weight not exceeding that of a carrier pigeon, for unless this can be satisfactorily accounted for, there is but little prospect of finding an available power, of sufficient energy in its application to the mechanism, for raising apparatus, either experimental or otherwise, in the atmosphere. In the second experiment, the screw-shaft made 240 revolutions, consequently, one vane

(there being two) was constantly passing over the *same spot* 480 times each minute, or eight times in a second. This caused a descending current of air, moving at the rate of near four miles per hour, almost sufficient to blow a candle out placed three feet underneath. This is the result of "slip," and the giving both a downward and rotary motion to this column of air, will account for a great part of the power employed, as the whole apparatus performed the work of a blower. If the wings, instead of travelling in a circle, could have been urged continually forward in a straight line in a fresh and unmoved body of air, the "slip" would have been so inconsiderable, and the pitch consequently reduced to such a small angle, as to add but little to the direct forward atmospheric resistance of the edge.

The small flying screws, sold as toys, are well known. It is an easy matter to determine approximately the force expended in raising and maintaining them in the atmosphere. The following is an example of one constructed of tin-plate with three equidistant vanes. This was spun by means of a cord, wound round a wooden spindle, fitted into a forked handle as usual The outer end of the coiled string was attached to a small spring steelyard, which served as a handle to pull it out by. The weight, or degree at which the index had been drawn, was *afterwards* ascertained by the mark left thereon by a pointed brass wire. It is not necessary to know the *time* occupied in drawing out the string, as this item in the estimate may be taken as the duration of the ascent; for it is evident that if the same force is re-applied at the descent, it would rise

again, and a repeated series of these impulses will represent the power required to prolong the flight of the instrument. It is, therefore, requisite to know the length of string, and the force applied in pulling it out. The following are the data :—

Diameter of screw - - -	$8\frac{1}{2}$ inches.
Weight of ditto - - -	396 grains.
Length of string drawn out -	2 feet.
Force employed - - -	8 lbs.
Duration of flight - - -	16 seconds.

From this it may be computed that, in order to maintain the flight of the instrument, a constant force is required of near sixty foot-pounds per minute—in the ratio of about three horse-power for each hundred pounds raised by such means. The force is perhaps over-estimated for a larger screw, for as the size and weight is increased, the power required would be less than in this ratio. The result would be more satisfactory if tried with a sheet-iron screw, impelled by a descending weight.

Methods analogous to this have been proposed for attempting aerial locomotion; but experiment has shown that a screw rotating in the air is an imperfect principle for obtaining the means of flight, and supporting the needful weight, for the power required is enormous. Suppose a machine to be constructed, having some adequate supply of force, the screw rotating vertically at a certain velocity will raise the whole. When the desired altitude is obtained, nearly the same velocity of revolution, and the same excessive power, must be

continued, and consumed *entirely in "slip,"* or in drawing down a rapid current of air.

If the axis of the screw is slightly inclined from the perpendicular, the whole machine will travel forward. The "slip," and consequently the power, is somewhat reduced under these conditions; but a swift forward speed cannot be effected by such means, for the resistance of the inclined disc of the screw will be very great, far exceeding any form assimilating to the edge of the wing of a bird. But, arguing on the supposition that a forward speed of thirty miles an hour might thus be obtained, even then nearly all the power would be expended in giving an unnecessary and rapid revolution to an immense screw, capable of raising a weight, say, of 200 pounds. The weight alone of such a machine must cause it to fail, and every revolution of the screw is a subtraction from the much-desired direct forward speed. A simple narrow blade, or inclined plane, propelled in a direct course at *this* speed—which is amply sufficient for sustaining heavy weights—is the best, and, in fact, the only means of giving the maximum amount of supporting power with the least possible degree of "slip," and direct forward resistance. Thousands of examples in Nature testify its success, and show the principle in perfection;—apparently the only one, and therefore beyond the reach of amendment, the wing of a bird, combining a propelling and supporting organ in one, each perfectly efficient in its mechanical action.

This leads to the consideration of the amount of power requisite to maintain the flight of a bird. Anatomists state that the pectoral muscles for giving

motion to the wings are excessively large and strong; but this furnishes no proof of the expenditure of a great amount of force in the act of flying. The wings are hinged to the body like two powerful levers, and some counteracting force of a *passive* nature, acting like a spring under tension, must be requisite merely to balance the weight of the bird. It cannot be shown that, while there is no active motion, there is any real exertion of muscular force; for instance, during the time when a bird is soaring with motionless wings. This must be considered as a state of equilibrium, the downward spring and elasticity of the wings serving to support the body; the muscles, in such a case, performing like stretched india-rubber springs would do. The motion or active power required for the performance of flight must be considered exclusive of this.

It is difficult, if not impossible, by any form of dynamometer, to ascertain the precise amount of force given out by the wings of birds; but this is perhaps not requisite in proof of the principle involved, for when the laws governing their movements in air are better understood, it is quite possible to demonstrate, by isolated experiments, the amount of power required to sustain and propel a given weight and surface at any speed.

If the pelican referred to as weighing twenty-one pounds, with near the same amount of wing-area in square feet, were to descend perpendicularly, it would fall at the rate of 1,320 feet per minute, being limited to this speed by the resistance of the atmosphere.

The standard generally employed in estimating power is by the rate of descent of a weight. Therefore,

the weight of the bird being twenty-one pounds, which, falling at the above speed, will expend a force on the air set in motion nearly equal to one horse (.84 HP.) or that of *five* men; and conversely, to raise this weight again perpendicularly upon a yielding support like air, would require even more power than this expression, which it is certain that a pelican does not possess; nor does it appear that any *large* bird has the faculty of raising itself on the wing *perpendicularly* in a still atmosphere. A pigeon is able to accomplish this nearly, mounting to the top of a house in a very narrow compass; but the exertion is evidently severe, and can only be maintained for a short period. For its size, this bird has great power of wing; but this is perhaps far exceeded in the humming-bird, which, by the extremely rapid movements of its pinions, sustains itself for more than a minute in still air in one position. The muscular force required for this feat is much greater than for any other performance of flight. The body of the bird at the time is nearly vertical. The wings uphold the weight, not by striking vertically downwards upon the air, but as inclined surfaces reciprocating horizontally like a screw, but wanting in its continuous rotation in one direction, and, in consequence of the loss arising from rapid alternations of motion, the power required for the flight will exceed that specified in the screw experiment before quoted, viz. : three horse-power for every 100 pounds raised.

We have here an example of the exertion of enormous animal force expended in flight, necessary for the peculiar habits of the bird, and for obtaining its food; but in the other extreme, in large heavy birds, whose wings

are merely required for the purposes of migration or locomotion, flight is obtained with the least possible degree of power, and this condition can only be commanded by a rapid straightforward course through the air.

The sustaining power obtained in flight must depend upon certain laws of action and reaction between relative weights: the weight of a bird, balanced, or finding an abutment, against the fixed inertia of a far greater weight of air, continuously brought into action in a given time. This condition is secured, not by extensive surface, but by great length of wing, which, in forward motion, takes a support upon a wide stratum of air, extending transversely to the line of direction.

The pelican, for example, has wings extending out ten feet. If the limits of motion imparted to the substratum of air, acted upon by the incline of the wing, be assumed as one foot in thickness, and the velocity of flight as thirty miles per hour, or 2,640 feet per minute, the stratum of air passed over in this time will weigh nearly one ton, or one hundred times the weight of the body of the bird, thus giving such an enormous supporting power, that the comparatively small weight of the bird has but little effect in deflecting the heavy length of stratum downwards, and, therefore, the higher the velocity of flight the less the amount of "slip," or power wasted in compensation for descent.

As noticed at the commencement of this paper, large birds may be observed to skim close above smooth water without ruffling the surface; showing that during rapid flight the air does not give way beneath them but approximates towards a solid support.

In all inclined surfaces, moving rapidly through air, the whole sustaining power approaches toward the front edge; and in order to exemplify the inutility of surface alone, without proportionate length of wing, take a plane, ten feet long by two broad, impelled with the narrow end forward, the first twelve or fifteen inches will be as efficient at a high speed in supporting a weight as the entire following portion of the plane, which may be cut off, thus reducing the effective wing-area of a pelican, arranged in this direction, to the totally inadequate equivalent of two-and-a-half square feet.

One of the most perfect natural examples of easy and long-sustained flight is the wandering albatross. "A bird for endurance of flight probably unrivalled. Found over all parts of the Southern Ocean, it seldom rests on the water. During storms, even the most terrific, it is seen now dashing through the whirling clouds, and now serenely floating, without the least observable motion of its outstretched pinions." The wings of this bird extend fourteen or fifteen feet from end to end, and measure only eight-and-a-half inches across the broadest part. This conformation gives the bird such an extraordinary sustaining power, that it is said to *sleep* on the wing during stormy weather, when rest on the ocean is impossible. Rising high in the air, it skims slowly down, with absolutely motionless wings, till a near approach to the waves awakens it, when it rises again for another rest.

If the force expended in actually sustaining a long-winged bird upon a wide and unyielding stratum of air, during rapid flight, is but a small fraction of its strength, then nearly the whole is exerted in overcoming

direct forward resistance. In the pelican referred to, the area of the body, at its greatest diameter, is about 100 square inches; that of the pinions, eighty. But as the contour of many birds during flight approximates nearly to Newton's solid of least resistance, by reason of this form, acting like the sharp bows of a ship, the opposing force against the wind must be reduced down to one third or fourth part; this gives one-tenth of a horse-power, or about half the strength of a man, expended during a flight of thirty miles per hour. Judging from the action of the living bird when captured, it does not appear to be more powerful than here stated.

The transverse area of a carrier pigeon during flight (including the outstretched wings) a little exceeds the ratio of twelve square inches for each pound, and the wing-surface, or sustaining area, ninety square inches per pound.

Experiments have been made to test the resisting power of conical bodies of various forms, in the following manner :—A thin lath was placed horizontally, so as to move freely on a pivot set midway; at one end of the lath a circular card was attached, at the other end a sliding clip traversed, for holding paper cones, having their bases the exact size of the opposite disc. The instrument acted like a steelyard; and when held against the wind, the paper cones were adjusted at different distances from the centre, according to their forms and angles, in order to balance the resistance of the air against the opposing flat surface. The resistance was found to be diminished nearly in the ratio that the height of the cone exceeded the diameter of its base.

It might be expected that the pull of the string of a flying kite should give some indication of the force of inclined surfaces acting against a current of air; but no correct data can be obtained in this way. The incline of the kite is far greater than ever appears in the case of the advancing wing-surface of a bird. The tail is purposely made to give steadiness by a strong pull backwards from the action of the wind, which also exerts considerable force on the suspended cord, which for more than half its length hangs nearly perpendicularly. But the kite, as a means of obtaining unlimited lifting and tractive power, in certain cases where it might be usefully applied, seems to have been somewhat neglected. For its power of raising weights, the following quotation is taken from Vol. XLI. of the *Transactions of the Society of Arts*, relating to Captain Dansey's mode of communicating with a lee-shore. The kite was made of a sheet of holland exactly nine feet square, extended by two spars placed diagonally, and as stretched spread a surface of fifty-five square feet. "The kite, in a strong breeze, extended 1,100 yards of line five-eighths in circumference, and would have extended more had it been at hand. It also extended 360 yards of line, one and three-quarters of an inch in circumference, weighing sixty pounds. The holland weighed three and a half pounds; the spars, one of which was armed at the head with iron spikes, for the purpose of mooring it, six and three-quarter pounds; and the tail was five times its length, composed of eight pounds of rope and fourteen of elm plank, weighing together twenty-two pounds."

We have here the remarkable fact of ninety-two and

a quarter pounds carried by a surface of only fifty-five square feet.

As all such experiments bear a very close relation to the subject of this paper, it may be suggested that a form of kite should be employed for reconnoitring and exploring purposes, in lieu of balloons held by ropes. These would be torn to pieces in the very breeze that would render a kite most serviceable and safe. In the arrangement there should be a smaller and upper kite, capable of sustaining the weight of the apparatus. The lower kite should be as nearly as practicable in the form of a circular flat plane, distended with ribs, with a car attached beneath like a parachute. Four guy-ropes leading to the car would be required for altering the angle of the plane—vertically with respect to the horizon, and laterally relative to the direction of the wind.* By these means the observer could regulate his altitude so as to command a view of a country, in a radius of at least twenty miles; he could veer to a great extent from side to side, from the wind's course, or lower himself gently, with the choice of a suitable spot for descent. Should the cord break, or the wind fail, the kite would, in either case, act as a parachute, and as such might be purposely detached from the cord, which then being sustained from the upper kite could be easily recovered. The direction of descent could be commanded by the guy-ropes, these being hauled taut in the required direction for landing.

The author has good reasons for believing that there

* This is a curiously accurate forecast of the Cody system of man-lifting kites which has been adopted by the military authorities.—[EDS.]

would be less risk associated with the employment of this apparatus, than the reconnoitring balloons that have now frequently been made use of in warfare.†

The wings of all flying creatures, whether of birds, bats, butterflies, or other insects, have this one peculiarity of structure in common. The front, or leading edge, is rendered rigid by bone, cartilage, or a thickening of the membrane; and in most birds of perfect flight, even the individual feathers are formed upon the same condition. In consequence of this, when the wing is waved in air, it gives a persistent force in one direction, caused by the elastic reaction of the following portion of the edge. The fins and tails of fishes act upon the same principle. In the most rapid swimmers these organs are termed "lobated and pointed."

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† The practical application of these suggestions appears to have been anticipated some years previously. In a small work, styled the "History of the Charvolant, or Kite Carriage," published by Longman and Co.. appears the following remarks:—"These buoyant sails, possessing immense power, will, as we have before remarked, serve for floating observatories. * * * * Elevated in the air, a single sentinel, with a perspective, could watch and report the advance of the most powerful forces, while yet at a great distance. He could mark their line of march, the composition of their force, and their general strength, long before he could be seen by the enemy." Again, at page 53, we have an account of ascents actually made, as follows:—"Nor was less progress made in the experimental department when large weights were required to be raised or transposed. While on this subject, we must not omit to observe that the first person who soared aloft in the air by this invention was a lady, whose courage would not be denied this test of its strength. An arm-chair was brought on the ground, then lowering the cordage of the kite by slackening the lower brace, the chair was firmly lashed to the main-line, and the lady took her seat. The main-brace being hauled taut, the huge buoyant sail rose aloft with its fair burden, continuing to ascend to the height of 100 yards. On descending, she expressed herself much pleased with the easy motion of the kite, and the delightful prospect she had enjoyed. Soon after this, another experiment of a similar nature took place, when the inventor's son successfully carried out a design not less safe than bold; that of scaling, by this

The tail extends out very wide transversely to the body, so that a powerful impulse is obtained against a wide stratum of water, on the condition before explained. This action is imitated in Macintosh's screw-propeller, the blade of which is made of thin steel, so as to be elastic. While the vessel is stationary, the blades are in a line with the keel, but during rotation they bend on one side, more or less, according to the speed and degree of propulsion required, and are thus self-compensating; and could practical difficulties be overcome, would prove to be a form of propeller perfect in theory.

In the flying mechanism of beetles there is a difference of arrangement. When the elytra, or wing-cases, are opened, they are checked by a stop, which sets them at a fixed angle. It is probable that these serve as "aero-

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powerful aerial machine, the brow of a cliff 200 feet in perpendicular height. Here, after safely landing, he again took his seat in a chair expressly prepared for the purpose, and, detaching the swivel-line, which kept it at its elevation, glided gently down the cordage to the hand of the director. The buoyant sail employed on this occasion was thirty feet in height, with a proportionate spread of canvas. The rise of the machine was most majestic, and nothing could surpass the steadiness with which it was manœuvred; the certainty with which it answered the action of the braces, and the ease with which its power was lessened or increased. * * * Subsequently to this, an experiment of a very bold and novel character was made upon an extensive down, where a wagon with a considerable load was drawn along, whilst this huge machine, at the same time, carried an observer aloft in the air, realising almost the romance of flying."

It may be remarked that the brace-lines here referred to were conveyed down the main-line and managed below; but it is evident that the same lines could be managed with equal facility by the person seated in the car above; and if the main-line were attached to a water-drag instead of a wheeled car, the adventurer could cross rivers, lakes, or bays, with considerable latitude for steering and selecting the point of landing, by hauling on the port or starboard brace-lines as required. And from the uniformity of the resistance offered by the water-drag, this experiment could not be attended with any greater amount of risk than a land flight by the same means.

planes," for carrying the weight of the insect, while the delicate membrane that folds beneath acts more as a propelling than a supporting organ. A beetle cannot fly with the elytra removed.

The wing of a bird, or bat, is both a supporting and propelling organ, and flight is performed in a rapid course, as follows:—During the down-stroke it can be easily imagined how the bird is sustained; but in the up-stroke, the weight is also equally well supported, for in raising the wing, it is slightly inclined upwards against the rapidly passing air, and as this angle is somewhat in excess of the motion due to the raising of the wing, the bird is sustained as much during the up as the down stroke—in fact, though the wing may be rising, the bird is still pressing against the air with a force equal to the weight of its body. The faculty of turning up the wing may be easily seen when a large birds alights; for after gliding down its aerial gradient, on its approach to the ground it turns up the plane of its wing against the air; this checks its descent, and it lands gently.

It has before been shown how utterly inadequate the mere perpendicular impulse of a plane is found to be in supporting a weight, when there is no horizontal motion at the time. There is no material weight of air to be acted upon, and it yields to the slightest force, however great the velocity of impulse may be. On the other hand, suppose that a large bird, in full flight, can make forty miles per hour, or 3,520 feet per minute, and performs one stroke per second. Now, during every fractional portion of that stroke, the wing is acting upon and obtaining an impulse from a fresh and undisturbed

body of air; and if the vibration of the wing is limited to an arc of two feet, this by no means represents the small force of action that would be obtained when in a stationary position, for the impulse is secured upon a stratum of fifty-eight feet in length of air at each stroke. So that the conditions of weight of air for obtaining support equally well apply to weight of air and its reaction in producing forward impulse.

So necessary is the acquirement of this horizontal speed, even in commencing flight, that most heavy birds, when possible, rise against the wind, and even run at the top of their speed to make their wings available, as in the example of the eagle, mentioned at the commencement of this paper. It is stated that the Arabs, on horseback, can approach near enough to spear these birds, when on the plain, before they are able to rise: their habit is to perch on an eminence, where possible.

The tail of a bird is not necessary for flight. A pigeon can fly perfectly with this appendage cut short off: it probably performs an important function in steering, for it is to be remarked, that most birds that have either to pursue or evade pursuit are amply provided with this organ.

The foregoing reasoning is based upon facts, which tend to show that the flight of the largest and heaviest of all birds is really performed with but a small amount of force, and that man is endowed with sufficient muscular power to enable him also to take individual and extended flights, and that success is probably only involved in a question of suitable mechanical adaptations. But if the wings are to be modelled in imitation

FIG 1

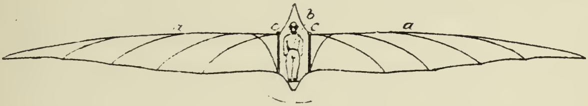


FIG 2

FIG 3

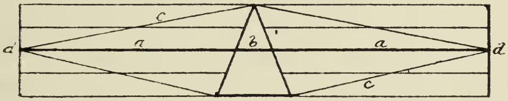


FIG 4

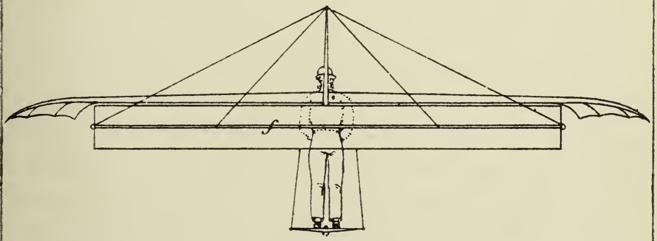
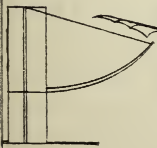
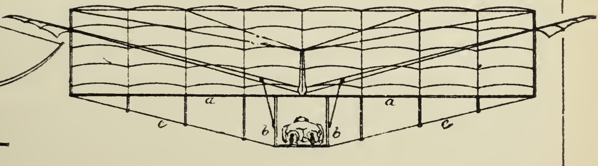


FIG 5

FIG. 6.





of natural examples, but very little consideration will serve to demonstrate its utter impracticability when applied in these forms. The annexed diagram, Fig. 1, would be about the proportions needed for a man of medium weight. The wings, *a a*, must extend out sixty feet from end to end, and measure four feet across the broadest part. The man, *b*, should be in a horizontal position, encased in a strong framework, to which the wings are hinged, at *c c*. The wings must be stiffened by elastic ribs, extending back from the pinions. These must be trussed by a thin band of steel, *e e*, Fig. 2, for the purpose of diminishing the weight and thickness of the spar. At the front, where the pinions are hinged, there are two levers attached, and drawn together by a spiral spring, *d*, Fig. 2, the tension of which is sufficient to balance the weight of the body and machine, and cause the wings to be easily vibrated by the movement of the feet acting on treadles. This spring serves the purpose of the pectoral muscles in birds. But with all such arrangements the apparatus must fail—*length of wing is indispensable!* and a spar thirty feet long must be strong, heavy, and cumbrous; to propel this alone through the air, at a high speed, would require more power than any man could command.

In repudiating all imitations of natural wings it does not follow that the only channel is closed in which flying mechanism may prove successful. Though birds do fly upon definite mechanical principles, and with a moderate exertion of force, yet the wing must necessarily be a vital organ and member of the living body. It must have a marvellous self-acting principle

of repair, in case the feathers are broken or torn; it must also fold up in a small compass, and form a covering for the body.

These considerations bear no relation to artificial wings; so in designing a flying-machine, any deviations are admissible, provided the theoretical conditions involved in flight are borne in mind.

Having remarked how thin a stratum of air is displaced beneath the wings of a bird in rapid flight, it follows that in order to obtain the necessary *length* of plane for supporting heavy weights, the surfaces may be superposed, or placed in parallel rows, with an interval between them. A dozen pelicans may fly one above the other without mutual impediment, as if framed together; and it is thus shown how two hundredweight may be supported in a transverse distance of only ten feet.

In order to test this idea, six bands of stiff paper, three feet long and three inches wide, were stretched at a slight upward angle, in a light rectangular frame, with an interval of three inches between them, the arrangement resembling an open Venetian blind. When this was held against a breeze, the lifting power was very great, and even by running with it in a calm it required much force to keep it down. The success of this model led to the construction of one of a sufficient size to carry the weight of a man. Fig. 3 represents the arrangement. *a a* is a thin plank, tapered at the outer ends, and attached at the base to a triangle, *b*, made of similar plank, for the insertion of the body. The boards, *a a*, were trussed with thin bands of iron, *c c*, and at the ends were vertical rods, *d d*. Between

these were stretched five bands of holland, fifteen inches broad and sixteen feet long, the total length of the web being eighty feet. This was taken out after dark into a wet piece of meadow land, one November evening, during a strong breeze, wherein it became quite unmanageable. The wind acting upon the already tightly-stretched webs, their united pull caused the central boards to bend considerably, with a twisting, vibratory motion. During a lull, the head and shoulders were inserted in the triangle, with the chest resting on the baseboard. A sudden gust caught up the experimenter, who was carried some distance from the ground, and the affair falling over sideways, broke up the right-hand set of webs.

In all new machines we gain experience by repeated failures, which frequently form the stepping-stones to ultimate success. The rude contrivance just described (which was but the work of a few hours) had taught, first, that the webs, or aeroplanes, must not be distended in a frame, as this must of necessity be strong and heavy, to withstand their combined tension; second, that the planes must be made so as either to furl or fold up, for the sake of portability.

In order to meet these conditions, the following arrangement was afterwards tried :—*a a*, Figs. 4 and 5, is the main spar, sixteen feet long, half an inch thick at the base, and tapered, both in breadth and thickness, to the end; to this spar was fastened the panels, *b b*, having a base-board for the support of the body. Under this, and fastened to the end of the main spar, is a thin steel tie-band, *e c*, with struts starting from the spar. This served as the foundation of the superposed aero-

planes, and, though very light, was found to be exceedingly strong; for when the ends of the spar were placed upon supports, the middle bore the weight of the body without any strain or deflection; and further, by a separation at the base-board, the spars could be folded back, with a hinge, to half their length. Above this were arranged the aeroplanes, consisting of six webs of thin holland, fifteen inches broad; these were kept in parallel planes, by vertical divisions, two feet wide, of the same fabric, so that when distended by a current of air, each two feet of web pulled in opposition to its neighbour; and finally, at the ends (which were each sewn over laths), a pull due to only two feet had to be counteracted, instead of the strain arising from the entire length, as in the former experiment. The end-pull was sustained by vertical rods, sliding through loops on the transverse ones at the ends of the webs, the whole of which could fall flat on the spar, till raised and distended by a breeze. The top was stretched by a lath, *f*, and the system kept vertical by staycords, taken from a bowsprit carried out in front, shown in Fig. 6. All the front edges of the aeroplanes were stiffened by bands of crinoline steel. This series was for the supporting arrangement, being equivalent to a length of wing of ninety-six feet. Exterior to this, two propellers were to be attached, turning on spindles just above the back. They are kept drawn up by a light spring, and pulled down by cords or chains, running over pulleys in the panels *b b*, and fastened to the end of a swivelling cross-yoke, sliding on the base-board. By working this cross-piece with the feet, motion will be communicated to the propellers, and by giving a

longer stroke with one foot than the other, a greater extent of motion will be given to the corresponding propeller, thus enabling the machine to turn, just as oars are worked in a rowing boat. The propellers act on the same principle as the wing of a bird or bat: their ends being made of fabric, stretched by elastic ribs, a simple waving motion up and down will give a strong forward impulse. In order to start, the legs are lowered beneath the base-board, and the experimenter must run against the wind.

An experiment recently made with this apparatus developed a cause of failure. The angle required for producing the requisite supporting power was found to be so small, that the crinoline steel would not keep the front edges in tension. Some of them were borne downwards, and more on one side than the other, by the operation of the wind, and this also produced a strong fluttering motion in the webs, destroying the integrity of their plane surfaces, and fatal to their proper action.

Another arrangement has since been constructed, having laths sewn in both edges of the webs, which are kept permanently distended by cross-stretchers. All these planes are hinged to a vertical central board, so as to fold back when the bottom ties are released, but the system is much heavier than the former one, and no experiments of any consequence have as yet been tried with it.

It may be remarked that although a principle is here defined, yet considerable difficulty is experienced in carrying the theory into practice. When the wind approaches to fifteen or twenty miles per hour, the lifting power of these arrangements is all that is requisite, and,

by additional planes, can be increased to any extent; but the capricious nature of the ground-currents is a perpetual source of trouble.

Great weight does not appear to be of much consequence, *if carried in the body;* but the aeroplanes and their attachments seem as if they were required to be very light, otherwise they are awkward to carry, and impede the movements in running and making a start. In a dead calm, it is almost impracticable to get sufficient horizontal speed, by *mere running* alone, to raise the weight of the body. Once off the ground, the speed must be an increasing one, if continued by suitable propellers. The small amount of experience as yet gained appears to indicate that if the aeroplanes could be raised in detail, like a superposed series of kites, they would first carry the weight of the machine itself, and next relieve that of the body.

Until the last few months no substantial attempt has been made to construct a flying-machine, in accordance with the principle involved in this paper, which was written seven years ago. The author trusts that he has contributed something towards the elucidation of a new theory, and shown that the flight of a bird in its performance does not require that enormous amount of force usually supposed, and that in fact birds do not exert more power in flying than quadrupeds in running, but considerably less; for the wing movements of a large bird, travelling at a far higher speed in air, are very much slower; and, where weight is concerned, great velocity of action in the locomotive organs is associated with great force.

It is to be hoped that further experiments will confirm

the correctness of these observations, and with a sound working theory upon which to base his operations, man may yet command the air with the same facility that birds now do.

DISCUSSION

The CHAIRMAN*: "I think the paper just read is one of great interest and importance, especially as it points out the true mechanical explanation of the curious problem, as to how and why it is that birds of the most powerful flight always have the longest and narrowest wings. I think it quite certain that if the air is ever to be navigated, it will not be by individual men flying by means of machinery; but that it is quite possible vessels may be invented, which will carry a number of men, and the motive force of which will not be muscular action. We must first ascertain clearly the mechanical principles upon which flight is achieved; and this is a subject which has scarcely ever been investigated in a scientific spirit. In fact, you will see in our best works of science by the most distinguished men the account given of the anatomy of birds is, that a bird flies by inflating itself with warm air, by which it becomes buoyant, like a balloon. The fact is, however, that a bird is never buoyant. A bird is immensely heavier than the air. We all know that the moment a bird is shot it falls to the earth; and it must necessarily do so, because one of the essential mechanical principles of flight is weight, without it there can be no momentum,

* The Duke of Argyll

and no motive force capable of moving through atmospheric currents.

"Until I read Mr. Wenham's paper, a few weeks since, I was puzzled by the fact that birds with long and very narrow wings seem to be not only as efficient flyers, but much more efficient flyers than birds with very large, broad wings. If you observe the flight of the common heron—which is a bird with a very large wing, disposed rather in breadth than in length—you will notice that it is exceedingly slow, and that it has a very heavy, flapping motion. The common swallow, on the other hand, is provided with a long and narrow wing, and I never understood how it was that long-winged birds, such as these, achieved so rapid a flight, until I read Mr. Wenham's paper. Although I do not profess to be able to follow the elaborate calculations which he has laid before us, I think I now understand the explanation he has given. His explanation of the action of narrow wings upon the air is, that it is precisely like the action of the narrow vanes of the ship's screw in water, and that the resisting power of the screw is the same, or nearly the same, whether you have the total area of revolution covered by solid surface, or traversed by long and narrow vanes in rotation.

"If Mr. Wenham's explanation be nearly correct, that supposing this implement (referring to a model) to be carried forward by some propelling power, the sustaining force of the whole area is simply the sustaining force of the narrow band in front. This, however, is a matter which will have to be decided by experiment. It certainly appears to explain the phenomena of the flight of birds. There are one or two observations in

the paper I do not quite agree with. Although I have studied the subject for many years, I have not arrived at Mr. Wenham's conclusion that the upward stroke of a bird's wing has precisely the same effect as a downward stroke in sustaining. An upward stroke has a contrary effect to the downward stroke; it has a propelling power certainly, but I believe that the sustaining power of a bird's flight is due entirely to the downward stroke. I should be glad to hear what Mr. Wenham may have to say upon this. My belief is, that an upward stroke must have, so far as sustaining is concerned, a reverse action to the downward stroke.

"Then with regard to another observation of Mr. Wenham's, that the tails of birds are used as rudders. I believe this to be an entire mistake; for if the tail of a bird could have the slightest effect in guiding, the vane of it must be disposed perpendicularly, and not horizontally, or nearly so, as at present.

"If you cut off the tail of a pigeon, you will find that he can fly and turn perfectly well without it. He may be a little awkward about it at first, but that is because he has lost his balancing power. We all know that it is a common thing to see a sparrow without his tail, therefore, I do not in the least believe that tails have any effect in guiding. They have an important effect in stopping progress, and, undoubtedly, that is one of the necessary elements of turning. If a bird comes close over your head, and is frightened, you will find his claws distended and his tail spread out as a fan, to stop the momentum of his flight. These are the only two observations with which I cannot agree; but as regards the explanation he has given as to the resistance offered

by long and narrow wings, he has made an important discovery."

Mr. WENHAM: "With regard to the wing not affording support to the bird during the upward stroke, some of the largest birds move their wings slowly, that is, with a less number than sixty strokes per minute. Now, as a body free to fall must descend fifteen feet in one second, whether in horizontal motion or not, it appears clear to me that there must be some counteracting effect to prevent this fall. When the wing has reached the limit of the down-stroke, it is inclined upwards in the direction of motion, consequently the rush of air caused by the forward speed, weight, and momentum of the bird against the under surface of the wing, supports the weight, even though the wing is rising in the upstroke at the time. In corroboration of my theory, I will read an extract from Sir George Cayley, who made a large number of experiments. He says, in page 83, of Vol. xxv., 'Nicholson's Journal':—'The stability in this position, arising from the centre of gravity, being below the point of suspension, is aided by a remarkable circumstance that experiment alone could point out. In very acute angles with the current, it appears that the centre of resistance in the sail does not coincide with the centre of its surface, but is considerably in front of it. As the obliquity of the current decreases, these centres approach and coincide when the current becomes perpendicular to the plane, hence any heel of the machine backwards or forwards removes the centre of support behind or before the point of suspension.'

"From this discovery, it seems remarkable that Sir

George Cayley, finding that at high speeds with very oblique incidences the supporting effect became transferred to the front edge, the idea should not have occurred to him that a narrow plane, with its long edge in the direction of motion, would have been equally effective. I may give another illustration. We all know, from our schoolboy experience, that ice which would not be safe to stand upon, is found to be quite strong enough to bear heavy bodies passing over it, so long as rapid motion is kept up, and then it will not even crack. We know, also, that in driving through a marshy part of road, in which you expect the wheels to sink in up to the axles, you may pass over much more easily by increasing the speed. In both these examples there is a greater weight passed over in a given time, and consequently a better support obtained. The ice will not become deflected; neither has the mud time to give way. At a slow speed, the same effect may be obtained by extending the breadth of the wheel. Thus, suppose an ordinary wheel to sink ten inches, if you double this width it will sink only five inches; and so on, until by extending the wheel into a long roller you may pass over a quicksand with perfect safety. Now, Nature has carried out this principle in the long wings of birds, and in the albatross it is seen in perfection."

The CHAIRMAN: "Paley has a passage, which is really very near the truth, on the flight of birds. But I think he misses it in some important respects. His explanation of the upward and downward stroke is, that they are not given perpendicularly, but that the upward stroke is 'feathered.' His idea is that the

upward stroke is given in some direction which avoids the reaction of the effect downwards, which would otherwise arise. Mr. Wenham also believes in a certain amount of feathering, in order to maintain an inclined plane in the air. There is nothing more difficult than to examine the phenomena of flight. I have often watched the heron, and I have never seen the slightest feathering in the air, and I do not believe the movement exists. I see, however, an elaborate contrivance, in the construction of the wings, which is made to meet the difficulty. The feathers are laid overlapping or underlapping each other; in the downward stroke the pressure tends to press the feathers together, and prevent the passage of the air; in the upward stroke the feathers are separated, and the air passes through them. In that way Nature has provided means for attaining the minimum and maximum resistance from the air."

Mr. Randles referred to the action of a man swimming; when, in the forward motion of the arms, the fingers would be open to allow the water to pass between; but when a stroke is given, the hand is closed, and the fingers drawn together, apparently to grasp the water.

Mr. Glaisher, upon being called upon by the Chairman, said: "I have not myself made many observations upon the flight of birds, and I scarcely feel myself qualified to give an opinion upon the matter, but I think it is a subject of very great interest indeed, and that the investigation of the laws of flight is a very proper one for this Society to take up. If it is taken up and carried out properly, it will increase our know-

ledge very much indeed. But, perhaps, your Grace, I may be permitted to say why I am here. It is well known that for the last three or four years the balloon has been the means of enabling me to take observations in the higher regions of the atmosphere. In the course of these experiments I have had a large number of communications made to me of different kinds, some of a very important nature; schemes, for instance, for lengthening the life of the balloon, and other appliances for giving more control over it.

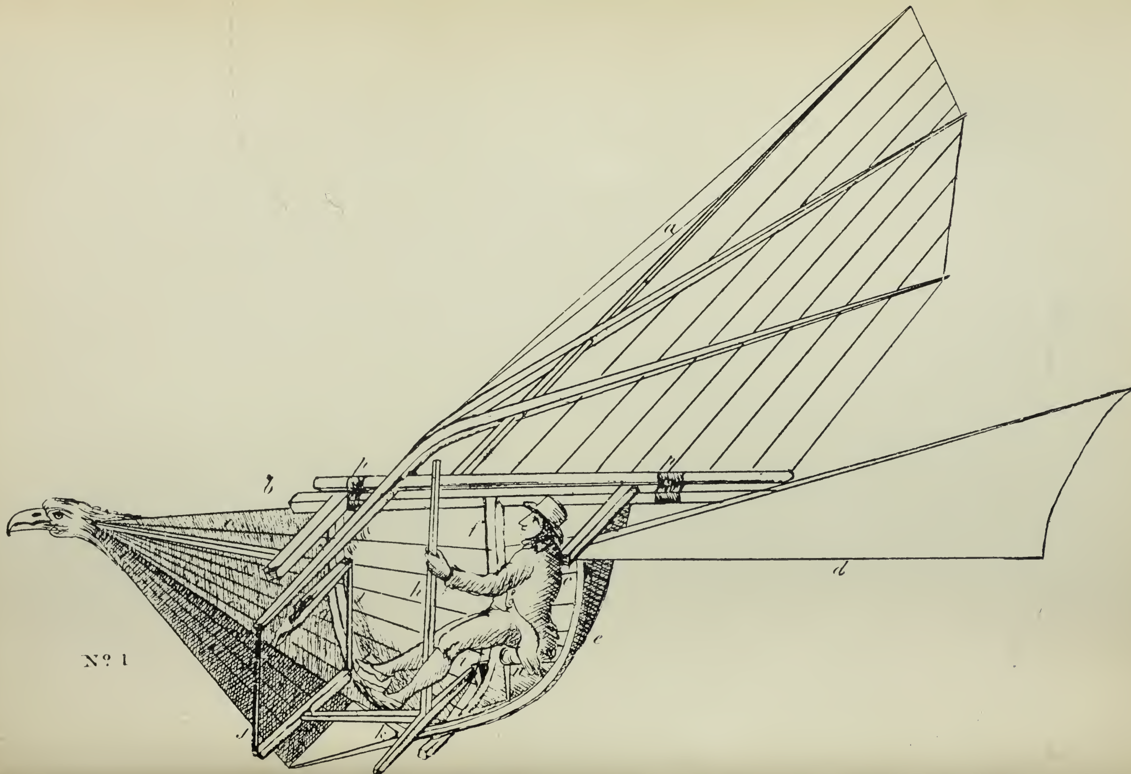
"Now, any gentleman who has been in the position of myself and my friend Mr. C. Green, the hero of 500 ascents, who I am glad to see present here this evening (cheers), will know that when we are five miles high, and engaged in these experiments, we are in no easy mind; so you will understand that I have felt great interest in those communications which have suggested plans by which we might economise the use of gas in the balloon. It has seemed to me exceedingly desirable that a society should be formed, through which suggestions such as these should have an opportunity of being brought forward and discussed. I feel that we cannot ignore the use of such a society. We all know that a great deal of time and energy is wasted in connection with the science of aërostation, and there are few instances in which the mechanical knowledge and ingenuity which its members could bring to bear upon such subjects could not be well applied."

The CHAIRMAN: "I should be glad if anyone would investigate the principle upon which fishes as well as seals and walruses are able to acquire such very rapid motion in a medium in which their specific gravity is

almost exactly the same. A bird acquires its momentum by its weight, which is a power in itself; but certainly this is not the case with fishes and other aquatic animals. Their specific gravity is nearly identical with the medium in which they move.

"We all know that a dead fish will maintain its equilibrium in the water for some little time, and afterwards float. This shows that the specific gravity of these animals is less than the medium in which they move. That is the only fact in Nature which leads me to believe it possible that balloons, not as now constructed, but a little heavier, might be made to make their way forward in the air. The practicability or the impracticability in the one and the other depends upon mechanical differences in the two media; and I think it is one which is well worthy the attention of men like Mr. Wenham and others."

The Art of Flying



Nº 1

Aeronautical Classics — **No. 3**

THE ART OF FLYING

BY

THOMAS WALKER

PRINTED AND PUBLISHED FOR

THE AERONAUTICAL SOCIETY OF GREAT BRITAIN,

By KING, SELL & OLDING, LTD, 27, Chancery Lane, W.C.

1910

First Published	. . .	1810	*Hull*
2nd Edition	. . . . .	1831	*Bristol*
Reprinted (1st *Ed.*)	. .	1877	12*th Ann. Rep. Aër. Soc.*
Reprinted (,,)	. .	1895	*Aer. Ann.* (*U.S.A.*)
Reprinted (1st & 2nd *Ed.*)		1910	*Aer. Classics*

Edited for the Council of the Aëronautical Society of Great Britain

by

T. O'B. HUBBARD & J. H. LEDEBOER

FOREWORD

History is silent concerning the life and circumstances of Thomas Walker, portrait painter of Hull. His sole claims to immortality are the two editions of his pamphlet upon flying, which exhibit him as an earnest amateur with a hobby and some small conceit of himself. He fumbles with great truths: knows much, but fails to order his knowledge, and hovers on the brink of great achievements in a way that is quite exasperating. For these reasons his writings are, perhaps, the most fascinating of all those of the pioneers, and this fascination is deepened by the drawings that accompany them. In the following reprint both his editions are published together for the first time. The first edition has been reprinted several times, but never with the original illustrations, which are here given from both editions.

It will be seen that between 1810 and 1831 his knowledge increased to a considerable extent. The drawings in the second edition are infinitely more practicable, and his machine bears a remarkable likeness to Professor

Montgomery's glider turned upside down. However, as neither of the models shown in fig. 3 and fig. 6 could have ever performed in the manner he describes, one is almost led to the supposition that, with the natural instinct for secrecy and mystery that in varying degrees every inventor possesses, he has purposely concealed the essential point of his discoveries and has designed the illustrations to bewilder rather than to elucidate. This theory is not pressed, but it is patent that his remarks are pregnant with the suggestion of greater knowledge—whether instinctive rather than realised, it is immaterial to decide.

It is, in fact, the suggestiveness of his work that renders Thomas Walker valuable, that gives him his recognised niche in history and crowns him with the sacred halo of the pioneer. All the little side-lights and minutiæ with which he entertains us are so sensible and so prophetic. He explains how steering can be effected by the shifting of the pilot's body, which, 80 years afterward, Lilienthal put to practical demonstration. The art of flying, he says, is as truly mechanical as the art of rowing a boat—a marvellous phrase for a century ago.

And if, in 1831, with the high courage of his convictions impaired by the burden of years, he allows himself momentarily to suggest that the insertion of gas between the upper and lower surfaces of the wings might render the result doubly sure, the lapse is immediately followed by a firm expression of opinion that this guarantee of success will not be necessary.

Though circumstances of birth and education caused him to be overshadowed by the florid genius of Cayley, the historian will see in the accident of Walker's writings a far greater earnest of the subsequent rise and apotheosis of the art of flying than in the more elaborate calculations of his brilliant contemporary.

N.B.—The square brackets in the following pages denote matter that appeared ONLY in the second edition.—Eds.

A

TREATISE

UPON THE

ART OF FLYING,

BY MECHANICAL MEANS,

WITH A

FULL EXPLANATION OF THE NATURAL PRINCIPLES
BY WHICH BIRDS ARE ENABLED TO FLY;

LIKEWISE

INSTRUCTIONS AND PLANS

FOR MAKING A FLYING CAR WITH WINGS, IN WHICH A MAN MAY SIT, AND, BY WORKING A SMALL LEVER, CAUSE HIMSELF TO ASCEND AND SOAR THROUGH THE AIR WITH THE FACILITY OF A BIRD.

ILLUSTRATED WITH PLATES.

By THOMAS WALKER,
PORTRAIT PAINTER, HULL.

HULL:

PRINTED BY JOSEPH SIMMONS, AT THE ROCKINGHAM-OFFICE;
AND SOLD BY LONGMAN, HURST, REES, & ORME, LONDON;
AND BY ALL THE PRINCIPAL BOOKSELLERS IN
TOWN AND COUNTRY.

1810.

A

TREATISE

UPON

ÆROSTATION;

OR, THE

Art of Travelling through the Air,

BY

MECHANICAL MEANS ALONE;

WITH A

FULL EXPLANATION OF THE NATURAL PRINCIPLES BY WHICH BIRDS ARE ENABLED TO FLY;

LIKEWISE

INSTRUCTIONS AND PLANS

FOR MAKING A FLYING CAR WITH WINGS, IN WHICH A MAN MAY SIT, AND, BY WORKING A SMALL LEVER, CAUSE HIMSELF TO SOAR THROUGH THE AIR WITH GREAT FACILITY.

ILLUSTRATED WITH PLATES.

BY THOMAS WALKER.

SECOND EDITION.

BRISTOL:

PRINTED BY WILLIAM HENRY SOMERTON, AT THE MERCURY-OFFICE,

AND MAY BE HAD OF THE AUTHOR.

1831.

DESCRIPTION OF THE *PLATES.**

THE SECTION OF THE CAR.

No. 1. *a* The right wing.—*b* One of the side rails, upon which the wing must work with two joints to admit of a vertical motion, for no other motion can answer the purpose.—*c c* The two cross bars which hold the side rails together.—*d* Half of the tail.—*e* The back rib, fixed to the middle of the hinder cross bar, and then brought down to the bottom of the middle rib.—*f* The middle rib, fixed to the two side rails, and *bended* down three feet below, to form the bottom of the car.—*g* One of the fore ribs, fixed to the fore corner of the car on the right side, and then to the back rib at the bottom.—*h* The upright lever, fixed into the crank, to move the wings with.—*i* The axis for the crank to work upon, which must be placed two feet nine inches below the top edge of the car.—*j j* Two iron rods two feet nine inches long, to unite the inner ends of the wings to the ends of the crank head.—*k* Two oblique prongs to be fixed to the back rib, projecting forward, with the points twenty inches asunder, and fifteen inches below the crank when it stands in a level direction. They are to keep extended the fore part

* This description refers only to the plates which appeared in the first edition, viz., Figs. 1 to 5. Figs. 6 to 12 (facing p. 33) were published, without description, in the second edition.—Eds.

of the bottom of the car, so as to admit of room for the crank head to work up and down.—*l* The crank, two feet six inches long; this causes the wings to strike up and down, by means of the man working the lever backwards and forwards.—*m* The crank head, eighteen inches long. —*n* The seat for the man to sit upon, fixed to the back rib.—*o* A piece of wood projecting from the middle of the fore cross bar, to which is fixed a head made of cork-wood, and a number of small cords to be stretched to the two fore ribs, and the prongs at the bottom of the car; in the same manner cords are to be fixed all round the car, to support the silk which covers the outside.—*p p* Two joints which fasten the wings to the edge of the car.

PLAN OF THE CAR.

No. 2. 1 1 1 1 The shafts of the left wing.—2 2 The two side rails which form the top edges of the car, and upon which the wings are to be fixed with two joints each.—3 3 Two cross bars three feet each, holding the two side rails together.—4 The middle rib with its two ends fastened to the side rails, bending down in the middle, so as to form the bottom of the car three feet below the top rails.—5 5 The two fore ribs to be united to the fore ends of the side rails, and to bend down to the middle rib, at the bottom of the car, and there joined to the back rib, which must have its upper end well fixed to the hindermost cross bar.—6 The seat for the man to sit upon, fixed with its front ten inches behind the axis of the crank.—7 7 Two foot-boards for the man's feet to rest upon.—8 The crank, two feet six inches long.—9 The head of the crank, eighteen inches long.—10 The axis of

the crank, eighteen inches long.—11, 12 Two iron rods, fixed with joints to the two inner ends of the wings, and then to the two ends of the crank head.—13, 13 Two shafts to give expansion to the tail.—14 Small cords to brace the fore shaft of the wings.—15 Eight longitudinal parallel cords, well stretched, to which slips of silk must be sewed, each slip about seven inches broad; and the oblique cords, 16, must be well stretched and knotted to them at each part where they cross.—17 A number of small threads, running across the under side of the wings at about four inches asunder, to which each slip of silk must be attached, that they may be prevented from opening more than half an inch from each other when the wings move upwards.

No. 3. A pair of paper wings, ten inches each in length, with a tail ten inches long down the middle; the frame or skeleton of the wings and tail to be formed of small sticks, about the thickness of a crow quill, and the paper must be fixed on by its edges being neatly pasted to the sticks; at the posterior angle of the wings the *paper* must have a piece of fine thin cloth pasted upon it to give strength to it at the corner.

No. 4. Represents a pigeon flying from the ground in the angle of sixty.

No. 5. Represents a grebe flying horizontally.

TO THE

Right Hon. Earl STANHOPE.

MY LORD,

AS far as an obscure individual like myself can judge of exalted characters, I am induced, in unison with public opinion, to hold a belief that your lordship is possessed, in a very superior degree, both of genius and a knowledge of the sciences, as well as a known predilection for everything that is calculated to improve and extend the mechanic arts, or to meliorate the condition of mankind. To acknowledge also that your lordship is equally preëminent in the senate is but paying a tribute which is *very justly due* to your patriotism, and the great exertions which you have made in advocating the cause of humanity. Every *friend* to his country must hold in grateful remembrance the energetic and manly opposition which your lordship evinced to prevent the commencement of a war more undefined in its object, more inefficient, and more direful and ruinous in its consequences to our country than any war it was ever madly and unjustly plunged into. My countrymen have *now* great cause also to remember, with indignation and deep regret, that, in return for your opposition to the origin of those baneful effects, which your lordship clearly foretold, and are now but too severely felt; in return for your wise counsels and patriotic zeal, your lordship met with every

B

coarse insult and contumely which blind folly and malice could suggest. But your lordship has this inestimable consolation that your life has been most *honourably* engaged not with the savage arts of murder, not with the burning of towns and the destruction of their inoffending and defenceless inhabitants; not with the filling of Europe with miserable widows and orphans; not with the ruin of manufactures and commerce, and the violation of the sacred constitutional rights and liberties of your countrymen; not with the low, base, and contemptible arts of any corrupt and venal faction; not with the arts of tyranny and oppression, or force and fraud; not with the machiavelian arts; but with the *noble arts* which are conducive to *peace*, *civilization*, and the *convenience* and *happiness of mankind.*

Had I invented a diabolical engine that would effectually have swept off from the earth a considerable portion of its *unwary* inhabitants, I should never have thought of addressing your lordship; I must have sought patronage from another quarter; but, considering the subject of this work, I thought no one was more able than your lordship to form a just estimation of its merits. I have, therefore, taken the liberty of dedicating it to you, flattering myself that the theory it contains will be honoured with your lordship's approbation which will greatly contribute to the pleasure of,

My Lord,

Your Lordship's humble Servant,

THOMAS WALKER.

Hull, February, 1810.

PREFACE.

I AM laying before the public a treatise upon a subject perhaps as extraordinary in its nature as anything that has lately come before them. [Since I first published my "Thoughts upon the Art of Navigating the Air," I have greatly improved my plan for accomplishing that desirable attainment; and, as the first edition is now out of print, I am induced to offer a second edition to the public, wherein I shall show how to produce a sustaining power upon the air, in a *two-fold* degree to what I had before discovered; also a plan for *perfect* steerage, with a very *superior* method for launching the machine upon the air;] and after a candid perusal, should it meet with approbation from the friends to arts and sciences, my utmost pride will be gratified. The flight of birds, although so common and familiar to our sight, is certainly as great a phenomenon as any in the creation; and artificial flying, when accomplished, may be considered as one of the greatest wonders of the mechanic arts, which I firmly believe attainable upon the plan I have suggested.

In this little work I have shown that birds' wings do not increase their expansion in exact ratio with the increased specific gravity of their bodies; I have given a demonstration of the cause of the projectile motion of birds, the discovery of a true knowledge of which has bid

defiance to philosophers in all ages, which, with other discoveries, I trust will prove that I have given consistency to what henceforth may be denominated the *science* of flying, and which may alone be deemed of considerable importance to science, had nothing more than that been brought forward; but as I have gone much further, and have advanced arguments, and given plans to render the *art of flying practicable*, the importance of this little treatise becomes obvious, more particularly so if we take into consideration the various purposes to which artificial flying may be applied.

When my work was just ready for the press, I was much surprised at the account a friend gave me of what he had seen that day upon flying, in a monthly journal. I immediately procured a sight of it, and found it to be an ingenious paper written by Sir George Cayley, and I own I was astonished at the perusal. I conceived it to be very extraordinary that two persons, not having the least knowledge of each other, should be publishing their thoughts at the same time upon such a subject; nor was I less surprised to find the subject treated of there in a manner so rational and far superior to anything I have ever seen before. From what Sir George has thought, and the calculations he has made upon the subject, he is so sanguine in his belief that flying will be effected as to say, in one part of his paper, as follows: "I feel perfectly confident, however, that this noble art will soon be brought home to man's general convenience, and that we shall be able to transport ourselves and families, and their goods and chattels, more securely by air than by water, and with a velocity of from 20 to 100 miles per hour."—*Vide* Nicholson's Journal for November, 1809.

For my own part, whatever reason I may have to be sanguine of success, I have made a resolution to suppress in my work every thought that confidence could suggest beyond what I could give demonstration of, along with the clearest directions how to attain the end in view; thereby putting it out of the power of critics to say that the principles of my theory have not a good foundation.

Notwithstanding, from the novelty and singularity of the subject, I do expect to meet with a good deal of raillery and sarcasm. The wits will tell me that I am flighty, and the more serious and heavy part of mankind, who are too ponderous for such aerial flights, will express a disapprobation of my scheme; but I do not write for such folks, my sole aim is to deliver my thoughts to the public, in hopes that *men* of *genius* and *science* may turn their attention to a subject that may not before now have attracted their notice, that, by their aid and assistance, the art may be brought into practice; and, as this country stands unrivalled in arts, I hope we shall not be long without a Society for the encouragement of the art of flying. Columbus was laughed at when he talked of a continent beyond the Atlantic; but flighty as he might appear he found it, and *wise* men lost it!

[Since I published the first edition of this treatise, copies have been taken into Holland, Germany, France, America, and other countries; and in the *Literary Gazette*, of Sept. 11, 1830, there is a report of there being a Mr. Genet, in America, and three rivals in France, all busily employed in making machines for travelling in the air, and all are equally sanguine of success.]

A TREATISE, &c.

WE learn, from several authors, that, in different ages of the world, the art of flying has been attempted by various means, all of which have hitherto failed of success. When we take into consideration the different methods which are recorded to have been tried, we cannot be surprised that they have all failed, since, compared with what is contained in the following pages, they will obviously appear to be nothing more than mere whims and contrivances, all utterly destitute of the true nature and science of flying.

I am conscious that many of my readers, who have never been led to notice the remarks that many eminently learned men have made upon this art, will be tempted at the first sight of my title page to ridicule a treatise upon artificial flying; for there is not a more common saying, when a person has taken some great difficulty in hand, than that such a thing is as impossible to be done *as for one to fly in the air.* I do assure all such that my treatise is not founded upon a whim of the moment, but from mature deliberation on the display of nature. The study of the works of nature has been to me, during the greatest part of my life, a source of amusement and inexpressible delight. The natural history of birds has particularly occupied my attention, and that enviable faculty which

they possess of flying has greatly excited my curiosity, and led me to that study by which I have obtained *a true knowledge* of the mechanical principles by which they fly, a knowledge which I do not hesitate to declare has hitherto remained undiscovered, although it has heen the object of the study and contemplation of many of the most eminent philosophers of past ages.

That great observer of the works of nature, Solomon, did not overlook the subject of flying, but speaks of it in his book of *Proverbs*, xxx, 18, 19—" There be three things which are too wonderful for me, yea four, which I know not: *the way of an eagle in the air*, the way of a serpent upon a rock." I beg also to remind such of my readers as doubt the possibility of flying that many useful and valuable mechanical inventions, which are now complete and become common, would, a century or two past, have been treated as visionary or impracticable; or had they been accomplished at such periods their effects would have been attributed to witchcraft. I have not the least doubt of being successful in the art of flying, if I had it in my power to give it a fair trial. My invention for attaining the art is founded *entirely upon the principles of nature;* and although these principles are as old as the creation, they have never, until now, been properly attended to. How much are we indebted to the study of nature for discoveries of the greatest importance? and from this delightful study many more are yet to be expected.

The love of pleasure is natural to man, and to gratify this propensity he eagerly attends to every artificial entertainment that is offered to him. He resorts to theatres and operas, to Newmarket, and other haunts of vanity and folly, as if pleasure were nowhere else to be found;

at the same time what an inexhaustible fund of entertainment is overlooked by all but a few, although constantly displayed in the wonderful exhibition of the works of nature.

What a pity it is that minds of men are not more generally and forcibly struck with the pure and tranquil delights resulting from the universal study of nature. What riot, confusion, waste of time, loss of money and of health, might be avoided if this pleasing and truly-enlightening study could be made fashionable. What an infinite stock of ideas it would create; how much it would enrich the human mind, and afford matter for social conversation and entertainment far superior to the unimportant subjects which too generally occupy the minds and tongues of men.

I will now present my readers with some account of various schemes which have been tried to accomplish the art of flying, and shall show the cause of their insufficiency. I shall explain the natural mechanical means by which birds are enabled to fly, and my readers will then be able to judge how far my invention for flying corresponds with the natural science, and is thereby calculated to succeed. I shall show likewise the comparative difference between the specific gravity of the humming bird and the condor, also the different expansion of the wings. I shall compare the weight of a man with the weight of the condor, and thereby determine the necessary dimensions of a pair of wings which would enable a man to fly; and, lastly, I will explain an experiment which I have made in order to demonstrate the principles of artificial flying, and give directions for making a machine wherein a man may sit, and, by working a pair

of wings with a lever, be able to ascend into the air, and fly with as much safety and ease as a bird.

During the early part of my life I have dissected a great many birds, and since studied very minutely the mechanism of their wings, tails, and all the parts which they employ in flying.

I have long been accustomed to contemplate a bird as a living machine, formed by the Almighty Creator, either to run upon the earth, to dive in the waters, or to ascend into or fly through the air; and when I examine its various parts, and find such an exquisite display of wisdom in each being formed so perfectly to answer the use it is applied to; when I see the effect of the whole, that such a wonderfully organized animated piece of matter can quit the earth and soar aloft in the air, it appears to me a miracle, and I am struck with admiration.

It is now almost twenty years since I was first led to think, by the study of birds and their means of flying, that if an artificial machine were formed with wings, in exact imitation of the mechanism of one of those beautiful living machines, and applied in the very same way upon the air, there could be no doubt of its being made to fly; for it is an axiom in philosophy that the same cause will ever produce the same effect.

It is easy to demonstrate that a bird is no more able to fly than a man without the mechanical effect of wings;[1]

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[1] The ostrich, in the torrid regions of Africa; the emu, in the extensive plains of Paraguay, in South America, which, standing erect, is about seven feet high, its legs are three feet long, its thighs are nearly as thick as the thighs of a man, it runs so swift that the fleetest dogs are foiled by it; the cassowary and the dodo, in the Molucca Islands; and the penguins, in the Straits of Magellan and the South Sea Islands. All these birds are as utterly incapable of flying as a man, none of them being provided with wings for that purpose.—T.W.

therefore, when a man is furnished [with a car to sit in and] with a pair of wings large enough, and can apply them in the same manner as a bird does, and with sufficient power, there can be no reason to doubt of a man being able to fly as well as a bird. The machine which I have planned is as close a copy of the natural mechanism of a bird as artificial means will admit of; and when my readers are made thoroughly acquainted with both the natural and artificial means of flying, I flatter myself they will then be willing to acknowledge that my scheme is a very rational one, highly calculated to insure success in the accomplishment of the art of flying, one of the most extraordinary and desirable arts with which we can be acquainted.

Although I have, for many years, been extremely anxious to bring the machine into effect, and am very sanguine in my expectations of success (for I positively assert that flying cannot be accomplished on any other plan than the one I propose), I, unfortunately, have ever found myself unable, from my professional avocations and other circumstances, to put it in practice, or I should long since have made the experiment.

Finding, therefore, that to no purpose I have deferred, for a long time, its execution, which I deeply regret, and the prospect of the future being not more favourable, I am induced to publish my plan, in the hope that the lovers of the arts and sciences, when I have laid before them a scheme so practicable, will readily be induced, for the honour of science and our country, to contribute to the means of bringing it into practice, and demonstrate to their fellow mortals how they may gain a perfect dominion over another element.

In almost every nation where arts and sciences have flourished, persons have manifested a wish to discover the art of flying. In Rome and in Paris particularly different persons, and in ages remote from each other, have tried experiments with wings formed of various materials, which have been fastened to their arms, but none of them succeeded, there not being strength sufficient in a man's arms to enable him to fly with detached wings fastened to him, leaving the whole weight of his body unsupported.

Friar Bacon, who lived nearly five centuries ago, wrote upon the subject, and he affirms that the art of flying is possible; and many others have been of opinion that, by means of artificial wings affixed to the arms or legs, a man might fly as well as a bird.

The philosophers of the reign of King Charles the Second were much engaged with this art. The famous Bishop Wilkins, who, in 1672,* published a treatise upon flying, was so confident of its practicability, that he says he does not question but that in future ages it will become as common to hear a man call for wings when going a journey as it is now to call for his boots and spurs.

In the year 1709, as we gather from a letter published in France in 1784, a Portuguese, Friar de Gusman, applied to the king to encourage him in the invention of a flying machine. The principle upon which it was constructed, if indeed it had any principle, seems to have been that of a paper kite. The machine was in a form of

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* This is hardly correct. The 1st edition of "Mathematical Magic," of which the 2nd part entitled "Dædalus or Mechanical Motions" contained several chapters on the subject, appeared in 1648.—EDS.

a bird, and contained several tubes through which the wind was to pass in order to fill a certain sail, which was to elevate it; and when the wind was deficient the same was to be effected by means of bellows concealed within the body of the machine. The ascent was also to be promoted by the *electric* attraction of pieces of amber placed in the top, and by two *spheres* inclosing *magnets* in the same situation.

These silly inventions show the very low state of science at that time in Portugal, especially as the king, in order to encourage him in his further experiments in such an useful invention, granted him the first vacant place in his College of Barcelos or Santerim, with the first professorship in the University of Coimbra, and an annual pension of 600,000 reis during his life. Of this De Gusman it is also related that, in the year 1736, he made a wicker basket of about seven or eight feet diameter, and covered it with paper, which raised itself about 200 feet in the air, and the effect was generally attributed to witchcraft.

Mr. Willoughby, after observing that the pectoral muscles of a man, in proportion to his weight, are many degrees too weak for flying, recommends to him who would attempt the art with the desire of success to contrive and adapt his wings in such a manner that he may work them with his legs and not with his arms, because the muscles of the legs are much stronger.

The celebrated Lord Bacon wrote on the subject of flying, and believed it practicable, but it seems he could no more direct how it was to be done than any other who had written before him on the same subject.

Thus much, for the satisfaction of my readers, I have thought proper to make mention of what has been attempted in the accomplishment of this wonderful art; but were I to adduce all that has been said and done, at different periods of time, I could compile a large volume of that alone, which would answer no other end than that of curiosity, and to show that no one has ever understood the natural means of flying, which is the only knowledge that can guide us to the completion of artificial flying, and which I hope and trust will be clearly demonstrated in this treatise.

As I shall have occasion to refer to various birds, possessing different powers of flight, in illustration of my design, I here introduce the history of the condor, for the information of such of my readers as may not be acquainted with it.

The condor is a native of America, and hitherto naturalists have been divided whether to refer it to the species of the eagle or to that of the vulture. Its great strength and activity seem to give it a claim to rank among the former, whilst the baldness of its head and neck is thought to degrade it to a rank amongst the latter. It is, however, fully sufficient for our plan to describe its manners, form, weight, expansion, and power; we will therefore leave to nomenclators to decide upon its class. If size (for it is by much the largest bird that flies) and strength, combined with rapidity of flight and rapacity, deserve preëminence, then no bird can be put in competition with it; for the condor possesses, in a higher degree than the eagle, all the qualities that render it formidable not only to the feathered tribe, but to beasts, and even to man himself.

Acosta, Garcilasso, and Desmarchais assert that it measures 18 feet across the wings when expanded; its beak is so strong as to pierce the body of a cow; and it is positively asserted that two of them are capable of devouring that animal. They do not even abstain from attacking man himself; but, fortunately, there are but few of the species. *The Indians say that they will carry off a deer or a young calf in their talons as an eagle would a hare or rabbit, that their sight is piercing, and their manners terrific.* According to modern authors they only come down to the sea coast at certain seasons, particularly when it is supposed their prey fails them upon the land; that they then feed upon dead fish and such other nutritious substances as the sea throws upon the shore.

Condamine says he has frequently seen them in several parts of the mountains of Quito, and has observed them hovering over a flock of sheep; and he thinks they would, at one particular time, have attempted to carry some of them off had they not been scared away by the shepherds. Labat says that this bird has been described to him, by those who have seen it, as having a body as large as a sheep, and that its flesh is as tough and disagreeable as carrion. The Spaniards residing in that country dread its depredations, there having been *many instances of its carrying off children.* Mr. Strong, the master of a ship, relates that, as he was sailing along the coast of Chili, in the thirty-third degree of South latitude, he observed a bird sitting upon a high cliff near the shore, which one of the ship's company shot with a leaden bullet and killed. They were greatly surprised when they beheld its magnitude, for when the wings were extended they measured 13 feet from one tip to the other; one of

the quill feathers was 2 ft. $4\frac{3}{4}$ in. in length, and $1\frac{1}{2}$ in. in circumference.

Mons. Feuilleé, whose description alone is accurate, has given a still more circumstantial account of this amazing bird.

"In a valley of Illo, in Peru," says he, "I discovered a condor perched on a high rock before me. I approached within gun-shot and fired, but as my piece was only charged with swan-shot the lead was not heavy enough to bring the bird down. I perceived, however, by its manner of flying, that it was wounded, and it was with a good deal of difficulty that it flew to another rock about 500 yards distant on the seashore. I therefore charged again with the ball and hit the bird under the throat, which made it mine. I accordingly ran up to seize it; but even in death it was terrible, and defended itself upon its back with its claws extended against me, so that I scarcely knew how to lay hold of it. Had it not been mortally wounded I should have found it no easy matter to take it, but I at last dragged it down from the rock, and, with the assistance of one of the seamen, I carried it to my tent to make a coloured drawing of it. The wings of this bird, which I measured *very exactly*, were 12 ft. 3 in. (English) from tip to tip. The great feathers, which were of a beautiful shining black, were 2 ft. 4 in. long. The thickness of the beak was proportionable to the rest of the body, the length about 4 in., the point hooked downwards and white at its extremity, and the other part was of a black jet. The thigh bones were 10 in. long, the legs 5 in., the toes and claws were in proportion, and the legs were covered with black scales. The little nourishment which these birds find on

the coast, except when a tempest throws up some great fish, obliges the condor to continue there but a short time. They usually come to the coast at the approach of evening, stay there all night, and fly back in the morning."

I now proceed to describe the construction and application of the wings of a bird. How properly are they formed to fulfil the uses they were made for: The first is to expand, and by that means to give the bird a secure hold upon the air below it, which hold is always in proportion to the dimensions of the wings. The tail produces the same effect. We see that by means of a pair of wings and a tail duly expanded, in a perfectly *passive state* and aloft in the air, without any muscular motion, a bird procures a suspending power, which counteracts the specific gravity of its body, and prevents it being precipitated to the ground; such is the effect of the wings and tail when in a *passive state.*

I will next take some notice of the quill feathers, which are replete with proofs of the wisdom of the Almighty artist who made them. As they were intended to swim within so light and subtle a fluid as the air is, it was necessary that they should be formed of the lighest materials imaginable; and as they were intended to strike upon the air with great power and rapidity, it was requisite that they should possess in the shafts great strength with elasticity; it was expedient too that the quill feathers should separate and open to let the upper air pass through the wings, to facilitate their ascent when they are struck upwards; it was also necessary that they should all shut close together, forming each wing into a complete surface or web, when they are, by the muscular power of

the bird, forced down in order to give a more secure hold upon the air below, and by that means keep the bird up.

Now if we do but examine the quill feathers we shall find in the shafts astonishing strength with elasticity, and very little specific gravity indeed. The webs of the quill feathers are broader on one side of the shaft than the other, which causes them to open as the wings move up and to shut as they come down, exactly answering the purposes I have already mentioned; therefore, we see how wonderfully-complete the wings are in all their parts, and how effectually they serve all the uses required.

I will now show the application and effect of the wings and tail in *an active* state. When a bird, by the power of its pectoral and deltoid muscles, puts its wings into action and strikes them downwards in a perfectly vertical direction upon the air below, that air being compressed by the stroke of the wings makes a resistance, by its elastic power, against the under side of the wings, in proportion to the rapidity of the stroke and the dimensions of the wings, and forces the bird upwards; at the same time the back edges of the wing being more weak or elastic than the fore-edges, they give way to the resisting power of the compressed air, which rushes upwards *past the same back edges*, acting against them with its elastic power, and thereby *causes a projectile force*, which impels the bird forwards; thus we see that by one act of the wings the bird produces both *buoyancy* and *progression*. When the tail is forced upwards, and the wings are in action, the bird ascends, and forced downwards it consequently descends; but the most *important use of the tail is to support the posterior weight of the bird*, and to prevent the vacillation of the whole.

Thus having discovered and explained to my readers the natural mechanical means by which birds accomplish flying, they will be able to see that the plan upon which I have formed my scheme for artificial flying is perfectly analogous to the principles of nature, which certainly ought to be clearly understood, and taken as our only guide, before we can ever expect to arrive at success in the art of flying; but with the knowledge of these principles *there cannot remain a doubt of success.*

When we first think of a man attempting to fly by mechanical means, we are induced, considering his specific gravity, to pronounce it impossible; and had we never seen or known of any bird larger than a humming bird, whose weight does not exceed one drachm, and whose diminutive wings measure only three inches from tip to tip; and were to be told by some traveller that he had seen a bird with a body as large as a sheep, that had wings of twelve feet expansion, and that it could quit the earth and ascend into the air with its ponderous body, and there fly about with as much ease as the little humming bird, we should think it too marvellous a tale to be credited. But as we are accustomed to see, almost every day, birds of such various dimensions and specific gravity as are exhibited by nature, from the humming birds to the common wren; from the wren, through a numerous gradation, up to the eagle, we can readily give credit to the history of the wonderful condor in South America, whose existence is so well attested that we can have no reason to doubt of it, more especially as we witness so vast a gradation in the indigenous birds of our own country. I believe that there were two of these prodigious birds in the Leverian Museum [and I have seen one exhibited in a caravan of wild beasts.]

The following observations upon the wonderful difference in the weight of some birds, with their apparent means of supporting it in their flight, may tend to remove some prejudices against my plan from the minds of some of my readers. The weight of the humming bird is one drachm, that of the condor not less than four stone. Now, if we reduce four stone into drachms, we shall find the condor is 14,336 times as heavy as the humming bird. What an amazing disproportion of weight! Yet by the same mechanical use of its wings, the condor can overcome the specific gravity of its body with as much ease as the little humming bird. But this is not all. We are informed that this enormous bird possesses a power in its wings, so far exceeding what is necessary for its own conveyance through the air, that it can take up and fly away with a whole sheep in its talons, with as much ease as an eagle would carry off, in the same manner, a hare or a rabbit. This we may readily give credit to, from the known fact of our little kestril and the sparrow hawk frequently flying off with a partridge, which is nearly three times the weight of these rapacious little birds.

Let us attend to this subject a little further. Let us consider these wings of the condor, which, with a *mechanical action alone*, produce a power that is capable of carrying through the air both the bird and the sheep, weighing together not less than ten stone, which would then be 204,000 *times the weight of the humming bird!* When this is duly considered, with reference to my plan, what encouragement does it not give to prosecute the art of flying? particularly so when we consider that a man of ten stone weight, in a machine weighing two stone, will only exceed the weight of the condor *one-fifth*

part; this is a mere trifle compared with the astonishing difference there is between the humming bird and the condor.

The condor carries ten stone, with wings of twelve feet expansion from tip to tip; the humming bird carries one drachm, with three inches expansion; the common wren is three times as heavy as the humming bird, and has but one inch more of wing; a pigeon weighs 16 ounces, which is 256 times as heavy as a wren, and has only ten times more expansion of wing; the goatsucker is forty times as heavy, and has seven times the length of wing. I could here carry the same observations upon other birds to a very great extent, but the above are instances sufficient to prove that birds' wings are not multiplied in their length in the same proportion with the increased weight of their bodies; therefore, as a man weighing ten stone and his machine two, as I have already shown, will only exceed in weight *one-fifth part* of the weight of the condor and his prey; and as the wings of the condor are about twelve feet, suppose we make a pair of wings of silk one-fifth longer than they are, which will be about fourteen feet and a half, I am thoroughly persuaded they will be found amply sufficient, as they will far exceed the progressive increase of birds' wings.

By attending to the progressive increase of the weight of birds, from the delicate little humming bird up to the huge condor, we clearly discover that the addition of a few ounces, pounds, or stones, is no obstacle to the art of flying; the specific weight of birds *avails nothing*, for by their *possessing wings large enough*, and *sufficient power to work them*, they can accomplish the means of flying equally well upon all the various scales and dimensions which we see in nature.

Such being *a fact*, in the name of reason and philosophy why shall not a man with a pair of artificial wings, *large enough* and with *sufficient power to strike them upon the air*, be able to produce the same effect.

I shall, after a few observations, proceed to describe how a machine may be made with a pair of wings, and a lever to work them with, so that any person will be able to see how far it is calculated to answer the purpose for which it is intended. This machine may be considered as a large artificial bird, and the man placed in the inside as the vital or moving power. All the attempts hitherto made in the art of flying, by different persons, according to historians, have been mere childish whims, not in the least degree calculated to insure success. They each made a pair of detached wings, some of silk, some of leather, and some of sheet iron and various other materials; they fastened them upon their shoulders or arms; thus equipped, they placed themselves upon some eminence, such as a high tower or a church steeple, then took to their wings; but few of them were fortunate enough to escape without some injury.

It is utterly impossible for a man to fly with a pair of wings fixed to his shoulders or arms, with the whole weight of his body hanging down and depending entirely on his pectoral muscles for support. These muscles in a man are many degrees too weak to keep extended a pair of wings of sufficient expansion to effectually counteract the specific gravity of his body. Let a man suspend the weight of his body, with his arms extended, holding to an horizontal beam by his hands, and he will very soon find the insufficiency of the strength of his arm to support his weight. On the plan which I have conceived for flying

the want of strength in the arms is amply provided for. By furnishing a man with a car to sit in [with two passive surfaces fixed to it of sufficient extent], the whole weight of his body is supported by it, and as he sits much in the same manner as if he were rowing a boat, he is enabled to bring into action his *whole bodily strength*, which *far exceeds* the strength of his arms only, and by sitting in such a position his strength can be exerted [applied to the active wings] with a far greater force than in any other attitude whatever; he at the same time gains an *additional advantage*, in this plan of mine, by exerting his strength upon a lever.

The two greatest requisites for accomplishing the art of flying are these—first, *expansion of wings large enough* to resist, in a sufficient degree, the specific gravity of whatever is attached to them;* second, *strength enough* to strike the wings with a sufficient force to complete the buoyancy, and give a projectile motion to the machine. With these two requisites combined *flying must be accomplished;* and upon my plan there can be no doubt of wings [passive surfaces] being made as large as ever they may be wanted; neither ought we to doubt of a man's ability, exerting himself in the way I have described, to bring into action as great a degree of strength, in proportion to his weight, as the condor is possessed of. Therefore, if we are secure of these two requisites, and I am very confident we are, we may calculate upon the success of flying with as much certainty as upon our walking [*or* navigating the ocean].

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* In the second edition this sentence became: "first, *expansion of flat passive surfaces large enough* to reduce the force of gravity so as to FLOAT the machine upon the air with the man in it."—EDS.

When I first thought of artificial flying [*and* discovered that the projectile force of birds is caused by having their wings formed with great strength along the front edges, and with the back edges very weak and elastic], it occurred to me that it would be of some importance to try what effect a pair of [artificial] wings [made upon the same principles] would have upon the air, [expanded in a passive state] without any mechanical power to work them; I thought that if I were to suspend a weight from beneath them, they would prevent that weight from falling in a perpendicular line to the ground, [and at the same time dart forwards] and thereby demonstrate that the ideas I had conceived of the cause of the projectile motion of birds were well founded.

I therefore made the following experiment, to which I call the *particular attention of my readers*, as *it positively demonstrates the cause of the projectile motion.* I made a pair of small wings, of fine paper, and very small slips of wood to keep them extended, and fixed on a tail of the same materials, imitating, as near as I could, the wings and tail of a bird when expanded in a *passive state** (*vide* fig. 3). I then suspended a small weight from under them, with a piece of thread, exactly in the centre of gravity; I held them up as high as I could reach, then took away my hand, and left them flat upon the air, without giving any impulse to them whatever; and by the weight pressing downwards the air under the wings became, in some degree, compressed, and by its reaction against the under side and the *back edges* of the wings,

* In the second edition this sentence became: "I made a pair of small wings, of fine paper, and very small slips of wood extended along the front edges, with the back edges consisting only of paper, imitating, as near as I could," etc. (*vide* fig. 6).—EDS.

they were [sustained upon the air and] projected with an oblique descent from one end of the room to the other, carrying the weight all that distance, which, without the wings being of this particular construction, could not have been done.

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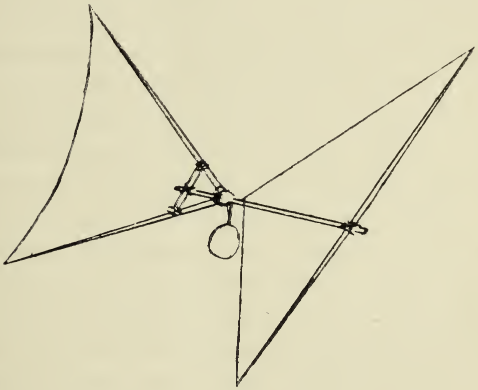


I had cause sufficient to exult in the success of my experiment which proved to me, in a very satisfactory manner, that what I had conceived to be the cause of the projectile motion of birds *was really the cause,* and that if I could but give a vertical motion to [a pair of] wings, so that they might strike upon the air with a sufficient force, they would then increase the reaction of the air [against the back edges], and instead of being projected in an oblique descent, totally overcome their specific gravity, and *continue flying in an horizontal direction.*

This is an experiment which any of my readers may make trial of for their own satisfaction and amusement [and that they may be better able to comprehend

me, I have given a representation of it in the plate annexed.] *

Another experiment, serving to show the different effect of buoyancy obtained by a parachute and by my paper wings, may be tried in the following manner:—Take two straight sticks, neatly dressed, about the thickness of a crow-quill and each about sixteen inches long, lay them across each other in the middle, at right angles, and tie them fast with a piece of thread; then tie a piece of thread from the ends of one stick to the other, so as to secure them at right angles; then take a sheet of gauze paper, and fasten all the four corners of it to the four ends of the sticks; but previous to this, paste upon the four corners of the paper four small slips of thin cloth in order to give sufficient strength; then suspend any small weight by a thread from the centre; let the whole fall from a height, and you will see the effect of a parachute in miniature; but this effect is very different from that of the paper wings; the parachute *sinks gradually down in a perpendicular line*, while the wings *dart forwards* to the distance of several yards.†

I have met with persons who have boldly asserted that it is impossible for a man to exert sufficient strength to raise himself up into the air by mechanical means alone; but the rashness and fallacy of such an assertion is com-

* *Vide* Fig. 6.

† In the second edition the following directions are given: "Take two straight sticks, neatly dressed, square, but tapering smaller from the middle to the ends, about three-eighths of an inch in thickness and each about sixteen or eighteen inches long, lay them across each other in the middle at right angles, and tie them fast with a piece of thread; then take a sheet of gauze paper, brush the sticks over with paste or gum, then stretch the paper well, and lay the sticks with the pasted side upon the paper; when it is dried upon the wood, suspend any small weight by four threads from the four ends of the sticks; let the whole fall," etc. —EDS.

pletely refuted and exposed by M. Degen, in Vienna, who has very lately actually ascended *into the air*, to a considerable height, by sitting in a machine and giving action to two parachutes ; and had he properly understood the principles of birds' wings, and considered the astonishing power in the reaction of the air, which may be *increased in proportion to any force* exerted upon it, *ad infinitum*, and possessed a complete knowledge of the principles upon which it enables birds to fly, he would have chosen wings and not parachutes, and might then have accomplished flying in perfection.[1]

There is no doubt that, by large parachutes, worked by a mechanical power, a man may raise himself from the ground to a considerable height; but that cannot be properly called flying, because as the compressed air rushes from underneath the parachutes, to regain its equilibrium *on all sides alike*, there can be no *projectile motion* effected, without which *there can be no command or steerage ;* [as that can *only* be obtained by going *through* the air without which] the whole apparatus will be driven whichever way the wind impels it ; I therefore cannot give credit to that part of the account of M. Degen's performance which asserts that he flew *in various directions*, although I can readily believe in his having raised himself into the air, and think that great praise is due to him. I do not believe it possible, upon his plan, that he could have gone

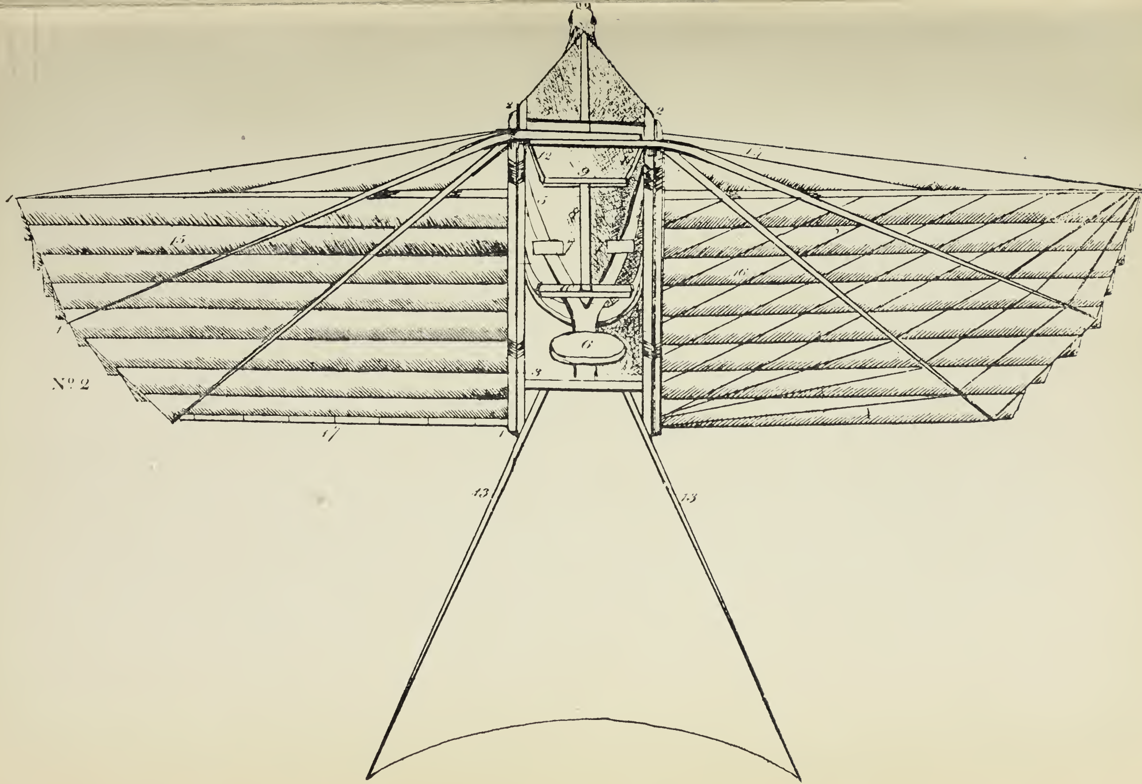
[1] M. Degen, a watchmaker of Vienna, has invented a machine by which a person may raise himself into the air. It is formed of two parachutes, of taffeta, which may be folded up or extended at pleasure, and the person who moves them is placed in the centre. M. Degen has made several public experiments, and rose to the height of fifty-four feet, flying, in various directions, with the celerity of a bird. A subscription has been opened at Vienna to enable the inventor to prosecute his discoveries.—*Vide* the Monthly Magazine for September, 1809.—T.W. (M. Degen obtained this result by fastening his wings to a small balloon which the Magazine reprehensibly omits to mention.—Eds.)

in any other direction than *with* the wind; but with a pair of wings constructed and worked according to the natural principles of flying, a projectile motion is obtained in as perfect a manner as buoyancy, *both of which* must be accomplished before we can have the benefit and pleasure of flying with *steerage*, and that upon the following plan only, viz.:—

Make a car of as light materials as possible, but with sufficient strength to support a man in it; provide a pair of wings of about eight feet each in length, let them be horizontally expanded, and fastened upon the top edge on each side of the car, with two joints each, so as to admit of a vertical motion to the wings, which motion may be effected by a man sitting and working an upright lever in the middle of the car; a tail of about seven or eight feet long, and the same breadth at its extremity, must be fixed to the hinder part of the car, and spread out flat to the horizon in the same manner as we see the tails of birds.*

The grebes, by their manner of flying, evince that the most important use of a bird's tail is *to support* the *posterior weight* of the body; for the Creator having left the whole of this class of birds, of which we have five different

* In the second edition the following directions were substituted: "Make a car of as light materials as possible, but with sufficient strength to support a man in it; provide a pair of wings, of about four feet each in length; let them be horizontally expanded, and fastened upon the top edge on each side of the car, with two joints each, so as to admit of a *vertical* motion to the wings, which motion may be effected by a man sitting and working an upright lever in the middle of the car. Extend in front of the car a flat surface of silk, which must be stretched out and kept fixed in a passive state; there must be the same fixed behind the car; those two surfaces must be both *perfectly equal* in length and breadth, and large enough to cover a sufficient quantity of air to support the whole weight as nearly in equilibrium as possible; thus we shall have a great sustaining power in those passive surfaces, and the active wings will propel the car forward."—EDS.



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species indigenous in this country, all totally destitute of any portion of a tail, they are, consequently, always seen when flying to have their bodies hanging down nearly in a perpendicular direction, and appear to fly with great difficulty; but this impediment in flying is of little consequence to them, their organization being perfectly adapted to their mode of living. They find their subsistence in lakes and pools, wherein they are incessantly diving, and, of course, are not obliged to fly until those places are

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frozen up, when they are compelled to flutter off, as well as they are able, in search of some spring or swamp which is not affected by frost, where they find a temporary subsistence until their favourite lakes are relieved from a surface of ice; they then return to their former haunts, when they again seem quite in their element. Here we find a class of birds, owing to their want of tails, possessing the power of flight in a very imperfect degree, compared with some birds. It also may be observed that birds having extraordinary large tails, as the magpie for instance, do not fly in the best manner; none of these birds possess what seems to constitute the excellence of flying, viz., soaring and reposing upon the air; this can only be effected when the weight of the body is upon an equipoise in the centre of the wings and tail, each bearing up its due proportion, and the expansion altogether so

large, as to bring the whole weight nearly in equilibrium with the atmosphere. This must be properly attended to in the construction of a flying machine.

To give a further security to the power of suspension, a sail of an equilateral triangle may be spread horizontally over the man's head, supported by a small light mast or bowsprit, at the height of three or four feet above the car; the sail must be expanded and fixed to the mast by a very light yard, presenting the base of the sail to the head of the car, with the opposite point towards the tail, and there fastened with a cord to another small bowsprit; this sail will be a protection, if large enough, in case of any accident occurring to the machine; it will then prevent the man from being precipitated to the ground in a manner similar to a parachute. I only have mentioned this sail that it may be resorted to if it be found necessary in a long voyage; the first experiment I would try without it.

A coachmaker is accustomed to make strong work with little weight of materials; he, therefore, would be the most proper person to make a machine of this kind. The man must sit in the middle, between the wings and the tail, so as to be a little behind the centre of gravity, for the purpose of causing a little preponderance of weight to act upon the back edge of the wings; for if there be not, in some degree, more weight behind than before, when the compressed air is making a resistance against the underside and back edges of the wings, where it rushes upwards again, causing a great reaction, it would, of course, elevate the hinder part of the car too much.*

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* This and the paragraph immediately preceding it are omitted in the second edition.—EDS.

The wings and the tail [passive surfaces] should be made of silk, very compactly woven, and [slightly done over with boiled linseed oil to make it] as impervious to the air as possible. The silk which the [active] wings are formed of should [perhaps] be laid on in separate broad slips,[1] and should open to admit the air to pass through as the wings move up, and close together again as they come down, in the same manner as I have described the action of the quill feathers in the wings of birds; although, upon the experiment being tried, this method may not be found so absolutely requisite, for we see flying squirrels, bats, butterflies, beetles, [and all other insects which fly, and] flying fish, etc., with wings formed of compact membranes, all flying exceedingly well. The Madagascar bat has a body the size of a rabbit, with wings four feet long, formed of entire membranes, and, although so large, it can fly as well as our little native bats; therefore it is possible that a pair of artificial wings may be formed without any valves [or slips], and yet answer equally well; but this can only be determined by actual trial.

It is necessary to observe that the car in which the man is to sit must be entirely covered on the outside [two sides] with silk or very thin leather, and along each side of the car the silk or leather must be *united* to the base of the wings, to prevent as much as possible the air from escaping anywhere but from the back edges of the wings; should that be neglected, when the air is compressed by

[1] The tail feathers of turkies laid close and parallel to each other and fast sewed upon eight pieces of strong riband, so as to form the same number of slips, then extended in the wing and well braced, would perhaps answer the purpose much better.—T.W. (This footnote is omitted in second edition.—EDS.)

the wings being struck downwards, it will rush upwards through the car and thereby fail of giving that resistance [*or* diminish that reaction of the air] against the underside [and back edges] of the wings which is necessary for the purpose of effecting buoyancy and progression.

I think that the *shafts* of the wings and tail would answer the purpose in the best manner, if they were each of them made of six long slips of thin whalebone, dressed tapering to a point, then wrapped together in a round form with small twine from end to end, and filled with cork along the inside.* By making them in this manner they would spring against the air, would be very light, and so strong that it would be impossible to break them with the power or weight of any one person. By forming them as above we shall humbly imitate the shaft of a quill feather, which is composed of a thin horny shell, containing a delicate light pith along the inside.

I here recommend my readers to *particularly observe* that a *main point in this treatise* is that they should not overlook the importance of the knowledge of the reaction of the air against the underside and *back edges of the wings*, for this is what causes the projectile motion, which is indisputably proved by the flying of my paper wings across a room, and which I will further illustrate by the flight of birds, mill sails, &c.

I have frequently conversed with persons about the art of flying by mechanical means, and generally found them disposed to treat the idea with ridicule. I have asked

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* This was altered in the second edition to: "I think that the *shafts* of the wings would answer the purpose in the best manner, if they were each of them made of two long slips of thin whalebone, dressed tapering to a point, then wrapped together with small twine, and with pieces of cork along the inside, at the distance of about six inches from each other."—EDS.

them if they knew how birds were enabled to fly, and they mostly answered me nearly in the following manner: that birds could fly because it was natural to them, that they were covered with feathers, which were such light materials as to help them to fly, and that their wings are properly adapted for flying. This was as far as they could explain, which proved that *all* they knew on this subject amounted to nothing. They generally seemed to indulge an idea that there was something in the flight of birds either supernatural or incomprehensible; but I hope my readers will be convinced, by this little treatise, that the art of flying is as truly *mechanical* as the art of rowing a boat.

[When I had convinced myself of having gained a *correct* knowledge of the cause of the projectile force of birds, I felt desirous of ascertaining how far it had been understood before; I therefore examined our encyclopedias, and all other philosophical books any way likely to contain the information I sought for; but nowhere could I find in print any light upon the subject; I was then induced to publish the knowledge of those principles, with instructions for making a car in accordance with the principles of nature, for the purpose of travelling through the air. Subsequent to my treatise being published, there has been printed a supplementary volume to the Encyclopedia Londonensis, wherein an explanation of the cause of the projectile motion of birds is inserted.]

I will here further illustrate how flying is effected. The air, when struck upon by wings, produces an effect by its reaction against the underside and back edges, similar to that which is caused by the wind blowing with

sufficient force against a mill-sail, when it *rushes off on one side*, and impels the sail to move, with this difference only, that the sail, being fastened at one end to an axis, is made to revolve, whilst the bird, being at full liberty in the air, is caused, by the expansive power of the air acting with a resisting force *against the back edges* of the wings, to glide forward in a right line.

Most of my readers, I think, will acknowledge the great elastic power of the wind, as it is manifested by the sailing of ships and the revolving of mill-sails; these effects are produced by the wind being compressed against the sails from its own natural motion and force; but the effect the air has against the wings or sails of birds is produced by its being compressed, with them striking vertically upon it; and the larger they are made the greater quantity of air is compressed, by which means is caused a more powerful reaction, and consequently a more effectual buoyancy and progression. From this cause all the birds whose wings are *very large* in proportion to their weight are able to fly with the *least exertion* imaginable, whilst birds with very small wings are obliged to use very great labour indeed; this being demonstrated by the examination of the dimensions of birds' wings and their specific gravity, and by observing the different methods of flying.

I have often been delighted with the striking conviction that Supreme wisdom alone could have so nicely adjusted all the various internal and external organization of the vast number of different species of birds, to their diversified wants and modes of living; but it is only necessary to observe here that all those which are under the greatest necessity of flying are provided with the

longest and *best proportion* of *wings* and *tails*, and are consequently able to fly in the best manner, and those which need them less have them more limited, and are therefore less capable of flying, as if the all-wise Creator had set limits to their powers of flight, that they might not go out of their respective elements.

Although I think that a pair of wings seven or eight feet each in length would be sufficient, still, if I could make it convenient to try the experiment of flying, and were not prevented, as I am, by a chain of untoward and uncontrollable circumstances, I would cause the wings to be made of as large dimensions as I could possibly *move with ease*.*

I observe amongst the aquatic birds that the auks, guillemots, divers, etc., have such remarkably small narrow wings that they would be utterly incapable of keeping themselves up in the air if it were not for an exertion which they are obliged to make in the extreme. Their wings are moved with such rapidity as to be with difficulty discerned. In this we see the economy of the all-wise Creator, for according to their habits and appetites they have very little occasion to fly at any time, except during the time of incubation, when they have to ascend the most inaccessible rocks and cliffs they meet with along the sea shore, where they breed and rear their young; all the rest of their time they pass on or in the water, swimming and diving for their food.

All the gallinaceous class of birds have very short concave wings, which they strike with great exertion; they also, in general, have but little occasion to fly; their food, which consists principally of grain and seeds, being spon-

* This paragraph is omitted in the second edition.—EDS.

taneously scattered over the earth, they are almost constantly upon their legs, running about to pick it up, and seldom fly but to avoid danger.

On the other hand, rapacious birds, whose appetites induce them to be the greatest part of their time upon the wing, in search of a subsistence which is very precarious (as every inferior bird, &c., to which they direct their sanguinary attacks, from that love of existence which God has so strongly implanted in all His creatures, will use its utmost skill and activity to elude its destroyer), are much better accommodated, having wings of large dimensions they can repose upon the air, and project themselves forward with a gentle wafting. This is the class of birds I would copy from in the construction of a machine for artificial flying. The kite or glead, P, B, Z, (or *milvus* from Lin.,) is the best natural specimen that we can find in the British ornithology; this bird has very large flat wings, with a large forked tail, and flies with the least exertion, I believe, of any bird in the creation.

All the hyrundo class of birds are almost constantly flying; they all have bodies of little weight, have large *flat* wings, and fly with great ease. The goat-sucker, which is a species of nocturnal swallow, is admirably constructed for flying with facility.

As I have mentioned aquatic birds, I will here take the opportunity of execrating, with all the indignation of my soul, that savage and brutal amusement which they bring to my mind, and which so many persons frequently practise and take delight in; I mean the shooting these harmless and inoffensive birds [merely for sport]. Many are the parties who resort to Flamborough-head, for no other purpose than gratifying their vanity by making a display

of their dexterity in shooting, and causing all the havock they possibly can amongst the poor inoffensive birds. Barren must be their minds, and callous their feelings, who can take pleasure in destroying these innocent creatures, which are not in the smallest degree offensive to man when they are living, nor of the least service to him when killed. If these GENTLEMEN could eat them when they have done shooting, that would be some excuse; but as their flesh is very rancid these wanton barbarians have no relish for their game. I wish their humanity was as nice as their appetites, they would not find delight in merely shooting them for sport and cruelty, leaving them, some killed and others wounded, floating on the surface of the sea, whilst their helpless young ones must consequently perish with hunger upon the shelvings of the rocks. Such amusements, surely, are not becoming rational beings, but may give pleasure to semi-rationals.

In the months of May and June these birds, which, during the rest of their time are dispersed over various parts of the ocean, are brought by one of the great impulses of nature to assemble at Flamborough-head in myriads, producing a throng, upon a great extent of cliff, similar to what we see in miniature in the front of a bee-hive, on a fine summer's day, when there is a perpetual egress and ingress of thousands.

A person who has never seen such a sight, and is capable of deriving pleasure from contemplating the economy and the works of nature, may find an exquisite gratification in paying a visit, at this season of the year, to Flamborough-head without having recourse to wanton acts of cruelty. Will there ever come upon the earth a genera-

tion of men who will despise all pleasures that are either unreasonable or inhuman?

Reason and *humanity* constitute the *only* permanent basis of all human happiness, and *real* honour and *true* glory of man! without which he is but a compound of folly and madness, and is too often a vile mischievous brute. By a disregard and contempt of these two divine guides families and nations become distracted and are made miserable, as we have too amply witnessed in the deplorable and wretched state in which Europe has been so long afflicted, where the appetite of the cannibal has *only* been wanting to complete the brutality of *civilized* nations. But I am departing too much from my original subject; I will withdraw my pen from this sickening view of poor, frail, erring, human nature!

After having described how to construct a machine to fly in, which, like the swift or great black martin (*apus*, Lin.), cannot fly from the surface of the ground, but must have an elevation to rise from, it becomes necessary that I should give directions how it may be made to ascend.* Set two tressels fast upon the ground, one six feet high and the other four and a half, at twelve feet distance

* The following directions were substituted in the second edition: "It becomes necessary that I should give directions how it may be launched upon the air, which may be done by various means; perhaps the following method may be found to answer as well as any: Fix a poll upright in the earth, about 20 feet in height, with two open collars to admit another poll to slide upwards through them, let there be a square platform made fast on the top of the sliding poll; place the car with a man in it upon the platform, then raise the platform to the height of about 30 feet by means of the sliding poll, let the sliding poll and platform suddenly fall down, the car will then be left upon the air, and by its pressing the air a projectile force will instantly propel the car forwards (fig. 9); the man in the car must then strike the active wings briskly upon the air, which will so increase the projectile force as to become superior to the force of gravitation; and if he inclines his weight a little *backward*, the projectile impulse will drive the car forward in an ascending direction (fig. 8). When the car is brought to a sufficient altitude," etc.—EDS.

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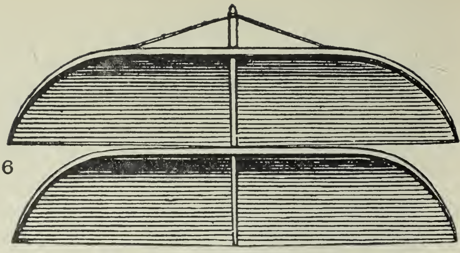

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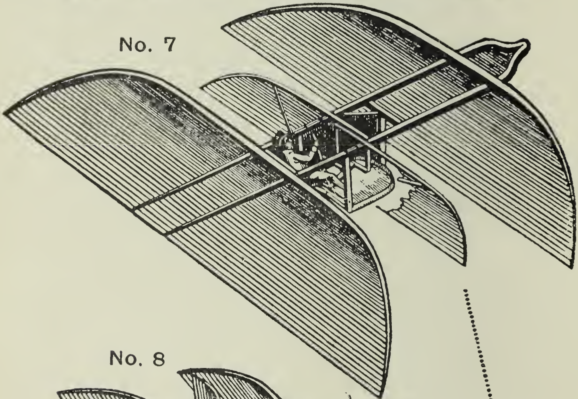

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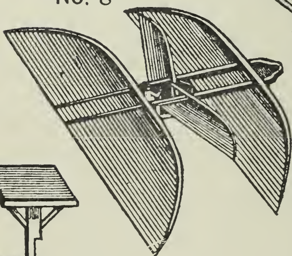

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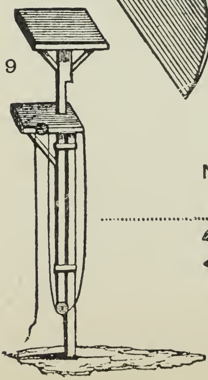

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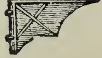

from each other; then lay upon them two or three planks, which will form a stage with an oblique plane, upon which the car must be placed, with its head pointing to the higher end of the stage.

A person may then get into the car, and sit a little behind the centre of gravity, which must be adjusted before the car is placed there; being thus elevated he will have depth enough on each side of the car to admit of his wings striking upon the air. He must then push the lever forward about eighteen inches from its perpendicular line, the tips of the wings will then rise three feet and a half above the level of their joints; he must then, with a brisk exertion, pull the lever backwards eighteen inches past the perpendicular line, and the tips of the wings will be struck downwards, passing through an arch of seven feet, and suddenly driving down and compressing the air in that arch, part of which will escape past the back edge of the wings (as I have described before), making at the same time a reaction which will push the wings forward: and as the car and the wings are first placed on an oblique plane, they will be impelled forwards, making an oblique ascent. The projectile impulse will naturally force the machine upwards in an angle in which the plane of the wings is laid, somewhat similar to what may be observed in the raising of a common paper kite, except in a right angle, or perpendicular line; but the nearer the angle of ascent inclines to the line of the horizon, the easier will the machine be found to ascend. I believe pigeons can ascend very nearly in a perpendicular line, but such an ascent would be too incommodious for artificial flying.

When the car is brought to a sufficient altitude to clear

the tops of hills, trees, buildings, &c., the man, by sitting a little forward on his seat, will then bring the wings upon an horizontal plane, and by continuing the action of the wings he will be impelled forwards in that direction. To descend, he must desist from striking the wings, and hold them on a level with their joints; the car will then gradually come down, and when it is within five or six feet of the ground, the man must instantly strike the wings downwards, and *sit as far back* as he can; he will by this means check the projectile force, and cause the car to alight very gently with a retrograde motion. The car, when up in the air, may be made to turn to the right or the left [by forcing out one of the fins, having one about eighteen inches long placed vertically on each side of the car for that purpose,* or perhaps] merely by the man inclining the weight of his body to one side.

When I have seen a man sitting in a chair upon a tight rope, with a table before him, spread over with decanters, glasses, &c., &c., and, by his *dexterity alone*, be able to keep himself and all his accommodations exactly balanced there while he sat smoaking his pipe, apparently at perfect ease, I have been induced to consider the art of managing a flying machine, compared with such a surprising display of human dexterity, to be very simple; and see no reason why men should not become as expert in navigating the air as the sea.

As some of my readers, who may have little regard for anything but the *utile*, may be induced to ask, what use will flying be of, when it is attained? I beg leave, in the way of reply, to give the following hints:—I hope it will

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* *Vide* Fig. 12.

be granted that flying will be of great use, if by such means we can have our letters, newspapers, &c., conveyed to any part of the kingdom at the rate of forty or fifty miles in an hour, or if that numerous class of mercantile agents who are now denominated riders, henceforth be enabled to glide through the air with great expedition, in flying machines; or if a man, by such means, can take a rope to any mariners in distress along the sea coast, and thereby become the happy instrument of saving their lives; and if the circumnavigator be able to quit his ship, fly and explore the interior parts of a new discovered island, free from the annoyance and hostilities of its rude inhabitants—but it would be tedious to enumerate all the uses to which artificial flying may be applied; it is obvious enough that when one man is enabled to fly, thousands may do the same, either on business or pleasure. It may tend greatly to reduce the vast number of horses kept in this kingdom, and by that means a very great quantity of land which is taken up at present in growing hay, oats, and beans for the support of these quadrupeds, might be then cultivated for the increase of our national stock of subsistence for the population; and I think it is evident that we have great occasion to reduce the superfluous number of those animals, and to employ all the land we possibly can to grow corn, &c., for our own subsistence. It is not improbable that some persons will ask if flying and all this can be accomplished, to which I answer that if my scheme for attaining the art be deemed a rational one, as I hope it will, I think we certainly ought to try the experiment.*

* This entire paragraph is omitted in the second edition.—EDS.

After the perusal of this work, I hope my readers will be fully convinced that all attempts which have been hitherto made in the art of flying have failed, not in consequence of the art being impracticable, but from the natural science of flying having never yet been fully understood. All that has ever been written and all the experiments that have ever been made towards attaining a knowledge of artificial flying by mechanical means display a chaos of unsettled thoughts very wide and deficient of the principles of nature ; but I hope it will be granted that I have clearly discovered and demonstrated the whole of those principles upon which flying depends, particularly the *cause* of the *projectile motion* of birds. This is a discovery of the greatest importance, for as the air is continually acting, in the manner I have described, against the back edges of the wings, and thereby impelling the bird forwards with great force, *it positively has as much tendency to overcome specific gravity as the expansion of the wings has.* This is a fact demonstrated very clearly by my paper wings and by the manner of flying peculiar to some birds, particularly the woodpeckers. When one of these extraordinary birds has struck its wings once or twice upon the air, and thereby produced a projectile impulse sufficient to force it forward to a considerable distance, it instantly contracts its wings *as close to its sides* as when perched on a bough, and continues flying several yards with its wings kept *close* in that position until the impulse is abating ; it then throws out its wings again, gives another stroke or two to renew the impulse, *shuts them up*, and is again driven forward ; thus continuing to fly by distinct and separate projectile impulses alone. Here then we see the great importance of a true

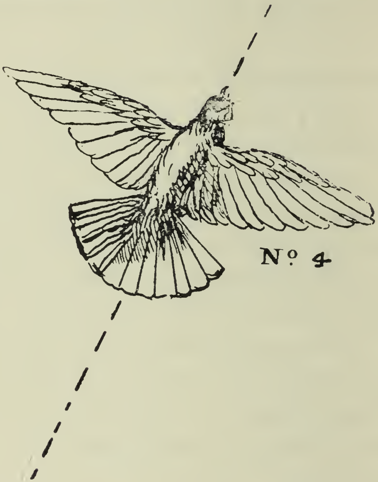
knowledge of the cause of the projectile motion of birds, for this surprising bird does not depend upon a continued expansion of wings to keep itself up in the air, but is kept up and carried forward by the projectile force alone!

The green woodpecker is about the size of a pigeon, and, as it is very common in every part of England where wood abounds, many of my readers may have an opportunity of observing its curious method of flying; the same may be observed of the beautiful little goldfinch, and of linnets. Here the physico-theologist, who is accustomed to contemplate the wisdom of God in all His works, might be led to infer that He has caused this deviation from the general method of flying, in order to demonstrate to us the *effect* of the projectile *force*, and that it is one of the *greatest essentials* in the art of flying, and perfectly distinct from and independent of the continued expansion of wings.

When we see pigeons flying *upwards* in the angle of *sixty* or *seventy*, as we do every day, from the streets to the tops of houses, with the plane of their wings parallel to the line of their ascent, I think they prove in a satisfactory manner the great effect of the *projectile force* [against the back edge of the wings]; for without we admit this to be the cause of their ascending in such angles, how can we possibly account for it in any other way, upon rational principles? *Vide* Fig. 10.

A stone thrown by the hand, and a ball ejected from the mouth of a cannon, are made to overcome specific gravity, and fly to a great distance; we all know that these are not kept up by wings, but entirely by the projectile force. In fact, it is by the air being made con-

tinually to push the bird forwards [by a projectile force, exceeding the force of gravity], which constitutes the main cause of flying.



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We must attribute to a total ignorance of the fundamental principles, that the art of flying has not been brought hitherto into common practice; for an art, so practicable as it is, must at any period of time have soon succeeded a discovery, such as I have made; and now that the art appears so very attainable, I hope that every friend to arts and sciences will acknowledge that it ought to have a fair trial.

I shall now conclude my treatise on flying with an appeal to the candour and good sense of my readers, whether the arguments I have used, and the principles upon which I have insisted the art of flying may be accomplished, are not such as give it a just claim to their approbation; for I think I may affirm, without being

accused of arrogance, that the art of flying has never before been treated of upon such rational and scientific principles.[1]

[I will offer an additional plan for ensuring success in navigating the air. Should it be found necessary, after giving the above plan a full and fair trial, to have an auxiliary power, the silk of the two extended passive wings may be put together *double*, and then inflated with hydrogen gas; this would increase the sustaining power but I firmly believe this will not be required.]

Having now submitted to the good sense of my countrymen the whole of what I intended on the subject of

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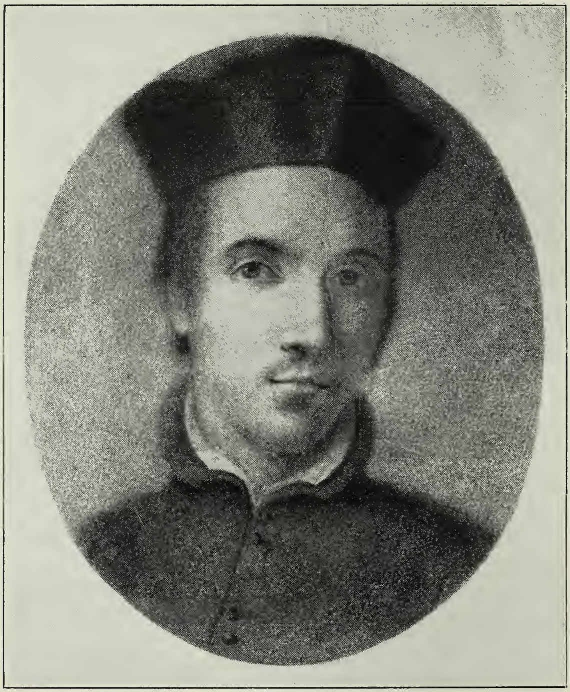
[1] I will here take the liberty of communicating a few hints, which I conceive to be of importance to the aerostatic science. Now that we know the true cause of the projectile motion of birds, and I having suggested a plan for producing the same effect by artificial means, we may be able to accomplish what Messrs. Roberts, Blanchard, and others attempted to do, but in vain, entirely from their not possessing a knowledge of this mystery of nature. I am alluding to the steerage of balloons, which they endeavoured, with great labour, to attain, by striking a number of oars *horizontally* against the air; and if we do but take into consideration that the balloon was constantly flying from the air against which they were striking, it does not seem probable that they could, by such means, produce the effect they aimed at.

But if we make a car from the plan which I have laid down in this treatise, and upon a scale large enough to admit of one of Messrs. Mead and Co.'s new invented revolving steam engines, to move the lever with, we then can work, in a *vertical direction*, a pair of *very large wings*, which would produce a *projectile force* sufficient to impel the balloon forward in any point of the compass to which we might incline it; and by having a large tail fixed to the car, in an universal joint, we should be able to give it any inclination whatever; and when we have thus effected a perfect steerage to balloons, we shall be able to convey a number of passengers to any place of destination with accuracy and safety. But for this kind of navigation the balloon must be much smaller than usual, and perfectly spherical, and the gas should be kept in such a degree as not to have too great a tendency to ascend—it should be so regulated as to float in equilibrium with the atmosphere; the aeronauts could then keep the machine at a moderate height—from fifty to a hundred feet would be high enough for ordinary sailing, and if it was found to be inclining too much upwards, it might be counteracted by holding the tail in a descending direction. One of Mr. Mead's patent steam engines can be made with a one-horse power, or equal to the strength of eight or ten men, *that will not weigh more than eight stone;* and will stand in the small space of four feet by two, with the boiler and all the apparatus belonging to it.—T.W. (This foot note was omitted in the second edition.—EDS.)

flying, I, for the present, most respectfully take my leave of them, indulging a hope that the prediction of Bishop Wilkins, expressed in a former page, will soon be verified, and trusting that I shall not be disappointed in the opinion I entertain respecting the patronage which they will extend towards the invention now laid before them. [As we have mining companies, steam-packet companies, canal companies, railway and steam-coach companies, gas-light companies, &c., &c., we shall not, *I hope*, be long without a company for establishing the art of flying by mechanical means.] Encouraged by the public, I shall not abandon my purpose of making still further exertions to advance and complete an art, the discovery of the *true principles* of which, I trust, I can with verity affirm to be exclusively my own.

The Aerial Ship

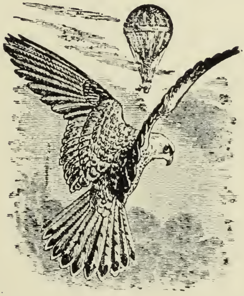


Aeronautical Classics — **No. 4**

The Aerial Ship

BY

FRANCESCO LANA



Printed and Published for
THE AËRONAUTICAL SOCIETY OF GREAT BRITAIN,
King, Sell & Olding, Ltd., 27, Chancery Lane, W.C.

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1910

ORIGINAL EDITIONS

1670	*Brescia* .	*"Prodromo overo Saggio, &c.," 5th & 6th Chaps. (Italian)*
1686	„ . .	*"Magisterium Naturae et Artis" Tome II., Lib. vi., Art. xlvi. (Latin)*

REPRINTS

1672	*Altdorf* .	*"Collegium Experimentale," by Joh. Christ. Sturm (Latin translation of "Prodromo," 6th Chap.)*
1676	*Rinteln* .	*"De Artificio Navigandi per aerem," by Philip Lohmeier (Latin: Sturm's translation)*
1695	— . .	*"De curiosis hujus saeculi inventis," by Geo. Paschius. (Latin: Sturm's translation)*
1760	*Brescia* .	*La Nave Volante. Dissertazione (Italian: Reprint of "Prodromo," 6th Chap.)*
1784	*Tübingen* .	*"Von der Luftschiffahrt" (German: Translation of the 6th Chap. and of Lohmeier)*
1784	*Rome* . .	*"Nuovo metodo per poter viaggiare in aria, &c." (Italian: Reprint of "Prodromo," 6th Chap.)*
1784	*The Hague*	*"Prodromo," 6th Chap. (Latin: Sturm's and Lohmeier's translations)*
1784	*Rinteln* .	*Lohmeier's Latin translation reprinted with a German translation*
1910	*London* .	*"Aeronautical Classics" No. IV. English translation of 5th and 6th Chapters of "Prodromo"*

Edited for the Council of the Aëronautical Society of Great Britain

by

T. O'B. HUBBARD & J. H. LEDEBOER

BIOGRAPHICAL NOTICE

Towards the end of the fourteenth century the noble family of Lana de Terzi emigrated from Bergamo and settled in the city of Brescia. Here, in a house of the Via Marsala, which is still in existence, there was born on December 10, 1631, to Count Gherardo Lana de Terzi and his wife, the Countess Bianca, *née* Martinengo, a son, Deodato Francesco Gioseffo, who was destined to make his name imperishable in the history of aerial navigation.

Francesco Lana's school days were spent at the Jesuit College of San Antonio; on November 11, 1647, he was received as a novice into the Society of Jesus in Rome. But like his illustrious contemporary, Blaise Pascal, whom he must have resembled physically no less than mentally, his mind was bent rather to the elucidation of the mysteries of science than to those of theology, and thenceforward we accordingly find him solely engaged in scientific research, although he re-

mained a pious member of the Jesuit Society until the end of his days. Indeed, his vows of poverty alone prevented him from carrying out many scientific experiments at a later day, and we shall hear his complaint that these very vows of poverty forbade him the expenditure of 100 ducats to build a model of his aerial ship.

From the year 1654 until 1657 Lana taught in the Grammar School at Terni, and here he made his solitary excursion into *belles lettres*—a drama published in 1656 under the title "La rappresentazione di San Valentino, martire e Prottetore di Terni, con la coronazione di Tacito, Floriano, Ternani, Imperatori Romani." From this time onward he entirely devoted himself to his scientific researches and held no further appointment, save during the years 1677 to 1679, when he taught as Professor of Mathematics at Ferrara. Settling down at Brescia in 1680, Lana spent his remaining years in the preparation of his scientific works, and in this city he died on February 22, 1687. In the records of the Society of Jesus his death called forth the following appreciation: "Vir plane religiosus et doctus ut ex ejus libris tum pietate tum eruditione plenissimus patet; praesertim vero in mathematicis disciplinis eximius."

The closing years of his life, clouded though they were with continuous illness, were well filled with scientific activity. In this period Lana founded the "Academia Brixiensis Philo-Exoticorum Naturae et Artis"—otherwise the Scientific Society of Brescia—of which he became President. Under his guidance this Society issued a series of interesting and valuable monthly reports.

Francesco Lana's scientific activity was enormous; his study of aerial navigation, indeed, forms but the merest fraction of his researches in almost every branch of science. He lived, in fact, in that delightful period when universality was yet attainable, and a single mind could still embrace the entire field of science in all its manifold aspects. In pursuing his researches, however, Lana's particularly honest mind came into constant opposition with the mass of unreliable information on which so-called scientific theories were then based, no less than with the total absence of proof of many phenomena which were successively accepted as true by one experimenter after another. He conceived, therefore, the project of re-writing the whole of science, but based now on actual experiment and incontrovertible proof. Of this immense work, written in Latin, and embracing the whole of scientific knowledge then available, only two volumes appeared during Lana's lifetime, under the title *Magisterium Naturae et Artis*, the first in 1684, the second in 1686. The third volume was not issued until 1692.

But some years earlier Lana had already published, in Italian, a shorter scientific treatise forming, as it were, a preliminary sketch of his great work. This book appeared in Brescia in 1670, entitled *Prodromo overo Saggio di alcune inventione nuove premesso all'arte maestra*, and contained in its 5th and 6th chapters—here reprinted in an English translation—the famous treatise on the Aerial Ship.

In the *Magisterium* the substance of these two chapters is incorporated under the heading Artificium XLVI. in the 6th Book of the second volume, and, save for a

single passage (given in the footnote, p. 14), contains no additional matter.

Of the "Aerial Ship" itself little need be said : impelled by the novelty and seeming impossibility of the subject no less than by his wonted passion for accuracy, Lana enters into every detail with what may seem unnecessary particularity at the present time. The origin of his project may, no doubt, be traced back to the discovery of atmospheric pressure by Torricelli, the barometrical researches of Pascal in France, and the experiments relating to the vacuum pursued in Germany by Otto von Guericke. Essentially, however, his invention is wholly and entirely original. Lana deserves the sole credit of discovering the principles of aerostation : owing to the practical difficulties of his invention, these principles were not, however, applied in practice until the end of the 18th century, when the investigation of the properties of gases provided a substitute for Lana's vacuum.

The only serious objection to Lana's proposed ship—the impossibility of building hollow globes of sufficient size and lightness and yet capable of withstanding atmospheric pressure when exhausted of air—would no doubt have been readily acknowledged by the inventor himself had he been granted the desired opportunity of making a practical experiment. The germ of his idea of a metal globe for navigating the air may be found in Albertus de Saxonia (1350) and Roger Bacon († 1294), and its fulfilment, through Dom Gauthey, Marey Monge, and Schwartz, in Zeppelin.* The discovery of

* Dom Gauthey proposed in 1783 to construct a balloon of copper, and to fill it with hydrogen by means of an internal bag of flexible material,

hydrogen gas, however, has rendered the "vacuum airship" unnecessary, however alluring a vision it may remain until even the present day.

Of the subsequent history of Lana's project but few details are deserving of mention. Two years after the appearance of the "Aerial Ship," J. H. Sturm published a Latin translation at Altdorf. This Latin translation was re-published, under the guise of an original work, by P. Lohmeier, at Rinteln, in 1676—an impudent piracy whose dishonesty has not, unfortunately, always been recognised. A picture published at Barcelona in 1678 also shows Lana's airship.

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which should serve to separate the gas introduced from above from the air as it was expelled below. But no one put the suggestion in practice, notwithstanding that M. Guyton de Morveau had recommended its trial, and that in 1837 Sir G. Cayley had expressed his belief that when gas vessels come to be used as permanent vehicles they will be made of "thin metallic sheets, kept firm by condensation with separate light bags of gas within" [*vide* "Aeronautics," Dec., 1909, p. 143. Footnote], till in 1843 M. Marey Monge undertook to make the experiment. And a magnificent experiment it was—costing its projector, single-handed, for sheer love of science, as he relates, the sum of 25,000 francs and 75 cents! In the notices which appeared in England of this machine it is spoken of as being of copper; it was, however, made of brass. . . . M. Monge states in undertaking this experiment he wished to ascertain whether the metal, being completely inalterable by the air and impermeable by the gas, would, when sufficiently thin, answer the purpose of the envelope for an aerial gas-vessel. In considering what metal he should select . . . he was apparently led to prefer the alloy with zinc to the pure copper, by the fact that thin brass plates were to be obtained from Prussia of a larger size, and with equal thinness, of better quality and of lower price, than were then made in Paris of either *cuivre rouge* or of *laiton*. Accordingly, he went to work with this German brass plate, 0·0001 mètre (equal to about ·004 inch) in thickness, and weighing 0·795 kilogrammes per square mètre (equivalent to 1·465 pounds avoirdupois per square yard); built him of it a hollow sphere 10 mètres (33 feet nearly) in diameter; lined it with two thicknesses of tissue-paper, glued surface to surface, and varnished with oil, and prepared to mount heavenward. (Mansfield, "Aerial Navigation," pp. 106-107.) The sphere leaked, however, could only be filled three-quarters full, and never moved. It ignominiously ended in the melting-pot.

The Schwartz aluminium airship is sufficiently modern (1897) to be recollected by most. Reference can be made to Valentine and Tomlinson's "Travels in Space," and the *Aëronautical Journal*, January, 1898.—EDS.

For the present edition—the first English translation—thanks are due in the first place to Dr. B. Wilhelm of Feldkirch, whose researches into the circumstances of the pioneers of aerial navigation, and of Lana in particular, have once and for all placed the entire subject on a sound basis and elucidated many obscure points. The greater part of what is known of Lana's history is due to Dr. Wilhelm's excellent work. Acknowledgment is also due to the valuable services of G. P. Deverall Saul, Esq., in connection with the translation from the original Italian.

THE AERIAL SHIP

I.

Showing in what manner it is possible to construct birds, which, of their own accord, can fly in the air.

CELEBRATED amongst writers was the pigeon, constructed by an ancient philosopher and mathematician named Archytas in such a manner that it sustained itself of its own accord and flew through the air. No writers have left us, however, any detailed account of the manner in which were arranged the different parts of the machine, whereby, although heavier in itself than air, it not only did not fall, but was enabled to fly. Some have thought that the pigeon of Archytas did not represent any different methods of construction than those by which Gio. Battista Porta in his "Magia Naturalis" instructs his readers how to make a dragon and to fly it in the air propelled by the wind, its movements being controlled by a cord—a thing nowadays well known, even by the children, but regarded in the time of Archytas as a new invention and, therefore, looked upon as a marvel. I should have been loth to believe it as true, had it not been for the writings of Aulus Gellius in the tenth book of his Attic Nights,

in which, citing the philosopher Favorinus in reference to this mechanical pigeon, he says: "Ita erat [scilicet] libramentis suspensum, aura spiritus inclusa atque occulta concitum."* What manner of flying bird could this have been, which was not outwardly propelled by the wind, but, rather, remained stable in the air by means of the force enclosed within it?

In like manner Adrianus Romanus recounts that Regiomontanus, the famous astronomer and mathematician, constructed an eagle which flew to meet Charles the Fifth on his solemn entry into the city of Norimberg, and, accompanying this monarch, returned and entered the city with him. Boetius also mentions certain small birds made with their wings like oars, that not only flew, but also sang. Glica and Manasse recount that other similar birds were in the possession of the Emperor Leone, and in more modern times we are told by our P. Famianus Strada that the distinguished engineer Turrianus made certain small birds fly in the halls of Charles the Fifth during the seclusion of his latter days after he had given up the reins of government into the hands of his son Philip.

Seeing that no one has handed down to posterity so ingenious and useful an art, it has seemed to me to be my duty to satisfy the curiosity of those versed in the art of mechanics by showing in what manner it is possible to imitate similar birds, which, I believe, may be done in several ways:—

Firstly: It can be done by means of small bellows

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* "Thus it was suspended by balancing weights and put in motion by the mysterious breath of the spirit hidden within." This passage cannot be translated intelligibly, and seems to have been obscurely framed by the writer with the intention of concealing his ignorance.—EDS.

actuated by toothed wheels. Having first constructed an eagle, pigeon, or other similar bird of the very lightest possible materials and making the wings of feathers or of other materials suitable to hold the wind, connect the same to the body of the pigeon in such a manner that they can be easily moved or flapped. Then in the body of the bird fit several toothed wheels which could be actuated by a spring mechanism such as is used for clocks; these wheels, in rotating, will elevate or depress two small bellows connected to the last wheel, which rotates the quickest, in such manner that whilst one is raised the other is depressed, which action is not difficult of accomplishment by those who understand the method by which similar wheels actuate the works or escapement of a clock. The wind from the bellows will be made to issue from two small tubes situated under the wings in the sides of the pigeon in such fashion that, striking against these wings, it will move at a certain speed, so that by beating and, in consequence, resisting the air, they will rise and give the machine the power of flight, which will last so long as the motion of the wheels and of the bellows continues. And this method seems to conform to that referred to by Aulus Gellius.

The second method is similar to the preceding one and consists in having a similar train of wheels, but instead of their moving the bellows, the escapement of the clockwork directly works the wings imparting a movement proportionate to the gravity of the machine, which is sufficient to lift it in the air and make it fly.

Thirdly: It would be feasible to condense air at a great pressure in a vessel or closed receptacle of

glass placed within the body of the pigeon, so that by opening the receptacle with a tap and allowing the air to escape through two small tubes to the underside of the wings its impetuous rush would lift the wings; but this action would be only of short duration and would very soon die away.

Fourthly and finally : It would be possible to raise a bird in the air in the same way as an egg-shell rises when filled with distilled dews and exposed to the hot rays of the sun, so that if a closed egg or bladder filled with a most volatile liquid were placed in the body of the bird, it could be easily rarefied by the heat of the sun and rise into the air.*

The above is, in these matters, as much as I purpose to indicate in order to show to other ingenious minds how they may perfect these inventions and discover others of a similar nature, and also to pave the way for the description of a yet more marvellous invention of mine, and that is

* This passage contains the germ of the hot-air balloon. For the egg-shell idea Lana is indebted to Lauretus Laurus (1650).—EDS.

II.

To construct a vessel that will float on the air propelled by oars and by sails, which may assuredly be done in practice.

THE preceding inventions did not exhaust the ardour or the curiosity of the human intellect, but have, rather, spurred it to seek how men could, after the fashion of the birds, also fly in the air; and it may not, after all, have been a myth what is related about Dædalus and Icarus, because it is stated as a fact that a certain person, whose name I cannot recall, has, in our time, and with a similar contrivance, flown across from one side to the other of the Lake of Perugia, although, when wishing to alight on the shore, he allowed himself to fall with so much rapidity that it cost him his life.* No one has, however, deemed it possible so to construct a vessel that it would travel on the air as if it were supported on water, insomuch that it has not been thought practicable to make a machine lighter than the air itself, which it is necessary first to do in order to accomplish the desired end.

Now I, who always had a bent for working out the most difficult inventions, after a long study over

* Giovanni Battista Danti (XV. Cent.). Other accounts say he fell on a church roof and broke his leg. *Vide* "Aëron. Jour.," 1909, p. 91; Chanute, "Progress in Flying Machines"; Tissandier, "La Navigation Aérienne."—Eds.

this, believe I have found the manner of making a machine lighter in itself than air, so that not only will it float on the air by its own lightness, but that it may also carry men and any other required weights; nor do I think it possible that I can be deceived, the whole thing being proven by tried experiment, while it can also be demonstrated as infallible from the 11th Book of Euclid, which is accepted by all mathematicians. I will therefore start by first making certain suppositions from which I will deduce the practical method of constructing the vessel, which if it does not deserve as did that one of Argus to be placed amongst the stars, yet will at least ascend upwards to them by its own efforts. I will, first of all, presuppose that air has weight owing to the vapours and halations which ascend from the earth and seas to a height of many miles and surround the whole of our terraqueous globe; and this fact will not be denied by philosophers, even by those who may have but a superficial knowledge, because it can be proven by exhausting, if not all, at any rate the greater part of the air contained in a glass vessel, which, if weighed before and after the air has been exhausted, will be found materially reduced in weight. Then I found out how much the air in itself weighed in the following manner. I procured a large vessel of glass, whose neck could be closed or opened by means of a tap, and holding it open I warmed it over a fire so that the air inside it becoming rarefied, the major part was forced out; then quickly shutting the tap to prevent the re-entry, I weighed it; which done, I plunged its neck in water, resting the whole of the vessel on the surface of the water, then on opening the tap the water

rose in the vessel and filled the greater part of it. I lifted the neck out of the water, released the water contained in the vessel, and measured and weighed its quantity and density, by which I inferred that a certain quantity of air had come out of the vessel equal in bulk to the quantity of water which had entered to refill the portion abandoned by the air. I again weighed the vessel, after I had first of all well dried it free of all moisture, and found it weighed one ounce more whilst it was full of air than when it was exhausted of the greater part, so that what it weighed more was a quantity of air equal in volume to the water which took its place. The water weighed 640 ounces, so I concluded that the weight of air compared to that of water was as 1 to 640, that is to say, as the water which filled the vessel weighed 640 ounces, so the air which filled the same vessel weighed one ounce.*

Secondly: I presuppose that a cubic foot of water, that is to say, the amount of water that is contained in a square vessel one foot wide and of the same height and depth, weighs 80 pounds or 960 ounces, which agrees with the experiments carried out by Villalpando, who in nearly all particulars confirms mine; I also found out that the water weighing 640 ounces was a little less than two-thirds of a cubic foot; from which it necessarily follows that if two-thirds of a foot of air weigh one ounce, a whole foot will weigh one ounce and a half.

Thirdly: I assume that any large vessel can be entirely exhausted of all, or, at any rate, of nearly all, the

* In the "Magisterium" Lana revises this estimate, and supposes the density of air to be $\frac{1}{960}$th of water.—EDS.

air contained therein, which, in my work on the Master Arts where I will describe them in their proper places, I will demonstrate can be done by various methods.* Meanwhile, so that it may not be said that it is only a vain promise on my part, I will here describe one of the more easy methods.

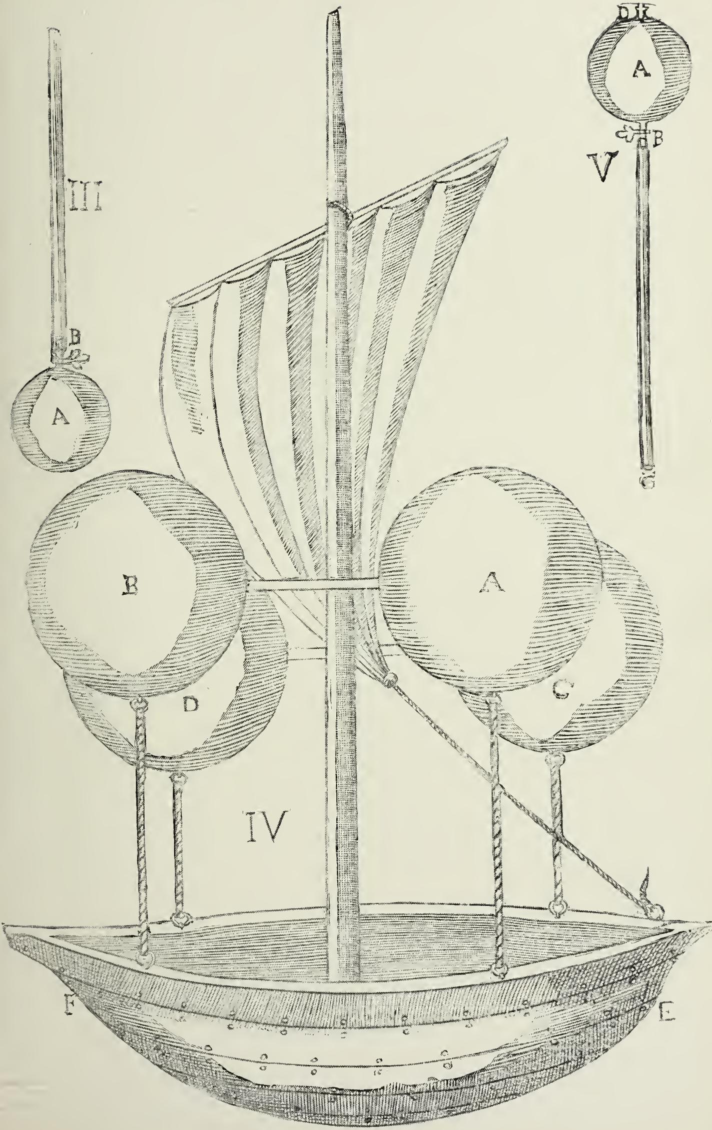
Procure any large vessel that is round and has a neck, and to the neck connect a tube of copper, or of tin, of at least the length of 47 modern Roman palmi, conforming to the dimension shown in Fig. III. at the end of this book after the treatise in telescopes** (see plate). The longer it is, the more certain will be the result. Close to the vessel, marked A, fix a small

* In this work, the following description is added of a method of constructing the globe from wooden laths:—

"Finally, I am of opinion that a sphere might be made out of very light wood such as is used in the manufacture of musical instruments. For if we examine the wood out of which a mandoline is made, we find that the back is of the thickness of a knife blade while its other dimensions constitute a square foot, and the weight is little more than two ounces. We know by experiment that a cubic foot of air weighs one and a half ounces; if, therefore, a sphere can be made ten feet in diameter, which according to the Archimedian laws on spheres and cylinders has a superficial area of 314 sq. ft., the total weight of this wooden globe exclusive of the air within will be 628 ounces. But the air contained therein will be 523 cubic feet, so that its weight will be very nearly 697 ounces; therefore the sphere will be lighter than an equal mass of air and will be able to rise in the air carrying with it a weight of 69 ounces—the difference between the weight of the wooden globe and that of an equal volume of air.

"Therefore make a perfectly round and solid globe of any kind of material and of the aforesaid size, and take thin oblong strips of the said wood and shape them on the outside of the solid globe, fitting them exactly, so that after they are dry they will retain their circular form. Each circle should have a breadth of two or three inches and be fashioned from one unjointed piece of wood. The largest circle should be made first, then the rest in couples growing gradually smaller, and finally all must be joined together with very strong glue in the same way as mandolines and other musical instruments are made. There will then be a perfect sphere which the strength of the air will be unable to crush or weaken. And if you are afraid that the air may enter owing to the porous nature of wood, you can smear the outside with some varnish.'—"Magisterium Naturae et Artis." Brescia: 1686. Tome ii., Lib. vi. Art. xlvi.

** In the present edition the plate faces this page.—EDS.



The Aerial Ship

tap B, which will close the vessel in such manner that no air can enter therein; fill the whole vessel as well as the tube with water, then close the tube at its extremity C, and turning the vessel upwards in such manner that it, the vessel, is uppermost, submerge the lower end of the tube C in water, and, whilst immersed in the water, open it, so that the water runs out of the vessel leaving it quite empty, but the tube remains full up to the height of 46 palmi 26 minuti, and all above it is empty. Then, no air being able to re-enter from any part, close the neck of the vessel by the tap B, and we shall have an empty vessel, and if anyone doubt it, weigh it and it will be found that as many cubic feet of water as have come out of it, so many times one-and-a-half ounces will it weigh less than it did before when full of air. Which proof suffices for my purpose, not wishing to dispute the matter any further here. The same applies to any kind of vessel of which I will speak in its proper place, demonstrating that it cannot be a vacuum, but at the same time showing that there will not be any matter left that can be of any weight.

Fourthly: Presuming to be correct and infallible the demonstrations in Book 11 and 12 of Euclid, accepted by all philosophers and mathematicians and shown to be true by experiment, in which it is proven, that the superficial area of globes increases in the proportion of the square of the diameter, whilst the volume increases in the proportion of the cube of the same diameter; and in order that this may be understood by all, it should be known that the proportions are duplicated when any three numbers are disposed in such manner that the third contains as many times the second as the latter

contains the first, as shown in the following example:

1	2	4
1	3	9
1	4	16

where the third number 4 contains the second number 2 as many times as two contains one, that is twice; and similarly the third number 9 contains the second number 3 as many times as the second contains the first, that is thrice, and so on.

It follows that the proportions are trebled when four numbers are disposed in such manner that the fourth contains as many times the third as the latter contains the second, and the third contains as many times the second as the latter contains the first, as shown in the next example:

1	3	9	27
1	4	16	64

Euclid thus demonstrates that the superficial area of globes or spheres increases as the square of the diameter, that is to say, if two globes are measured, one having its diameter double that of the other, for example, one a palmo in diameter, and the other of two palmi, the surface of the globe of two palmi will be four times larger than the surface of the other, and the entire mass or volume of the globe increasing in treble ratio, will be eight times larger, and, consequently, eight times heavier than the globe, inasmuch as the surface of the greater to the surface of the lesser will be as 4 to 1 and of the volume as 8 to 1. Which truth, besides the theoretical demonstration, can also be shown practically by weighing the water contained in a sphere of one palmo in diameter, and that in one of

two palmi, which will give us the triplicated ratio of the surface we can obtain by measuring the surface of the same spheres or vessels; this, in passing I may remark, gives one an economical rule for saving the cost of materials if, for example, we should wish to build wine casks, sacks, or other necessary vessels, inasmuch as if we build one large cask from the wood required to build two, that one cask will contain double the quantity of wine that could be contained by the two casks. Similarly if the canvas required to make two sacks be sewn together so as to only make one sack, this one sack will contain double the quantity of grain that could have been held by the two sacks.

Fifthly: I suppose, with all the philosophers, that when a body is lighter or has less density, as they describe it, than another, the lighter one will ascend in the heavier one if the heavier is a liquid body. As is the case of a wooden sphere, which ascends to the surface of the water and floats there, because it is lighter in density than the water, so also will a glass vessel full of air float on the water, notwithstanding that glass in itself is heavier than water, but all the substance of the vessel—taking the glass and air together—is lighter than an equal volume of water, which fact is owing to its being, as a whole, lighter in density than water.

Presupposing all these things, it is certain that one can construct a vessel of glass or other material which could weigh less than the air contained therein; if, then, one exhausted all the air in the manner before described, this vessel would be lighter in density than the air itself, and, therefore, by our fifth supposition, it would float on the air and ascend. For example, if

one could construct a vessel of glass of a size to contain a cubic foot of water equal to 80 pounds and yet so light that it weighed less than one ounce and a half, and if the air was exhausted from it (which by our first and second suppositions weighs only one ounce and a half) the vessel would remain lighter than air itself and would ascend in it, sustained therein by its own lightness. This vessel, capable of containing one cubic foot of water, yet so light that it only weighs less than one ounce and a half, cannot be made in glass or other material and yet be solid and firm, but if one was to construct a much larger vessel, say with double the surface of glass, one would have a vessel which would hold four times the quantity of water, that is, four cubic feet, and, consequently six ounces of air, as, by our fourth supposition, the capacity grows in double ratio of the surface. By constructing a vessel capable of containing four feet of air and yet weighing less than six ounces, on exhausting the six ounces of air it would again be lighter than air, and the construction of this second vessel would certainly be twice as easy as the construction of the first one. But inasmuch as even this second vessel may not be easily made light enough to weigh less than six ounces and yet contain four cubic feet of air, let another yet larger one be constructed, which should have double the capacity of the second one, that is, of eight cubic feet, and, consequently, of 12 ounces of air, which should weigh less than 12 ounces, and the construction of this third vessel would be easier than that of the second one. In effect one need only go on increasing the capacity of the vessel, because that will always increase in greater pro-

portion than its surface, that is, than the material of which it is made and its weight; so that one could ultimately get it to such a size that, although it be covered by a solid and relatively heavy material, yet the weight of the air contained therein will be more than that of the material forming the surface of the above vessel, because, as I have already shown, the capacity or size increases in double ratio to its surface.

Let us consider of what predetermined size it is possible to construct a vessel of copper beaten out thin, but not so thin as to be difficult to work, and let us suppose that the thinness of the copper be such that a sheet of the width and length of a foot weighs three ounces, which is not a difficult matter to do.* Let us, therefore, with this copper drawn out to such a thinness, make a round vessel the size or diameter of which is 14 feet. I contend that this vessel will weigh less than the air contained therein. If the latter be exhausted, the vessel, being lighter than its equivalent volume of air, will necessarily rise of itself and float in the air. To demonstrate this I will make use of the infallible rule of Archimedes for measuring a sphere. He lays down as a fact that the ratio of the diameter to the circumference of a circle is as 7 to 22 or rather less, so that if the diameter be seven feet the circumference or perimeter is 22 feet, so that in making our vessel of 14 feet diameter the circumference will be 44 feet, because as 7 feet is to 22 feet, so is 14 feet to 44 feet. To find out how many square feet there are in the

* The actual thickness of the copper-sheeting is given in the "Magisterium" as that of "nummi argentei majoris, seu scuti, vulgo duatone," that is, 2 to 3 millimetres.—EDS.

whole superficial area of the round vessel he tells us that its diameter should be multiplied by the circumference; multiplying, therefore, 14 by 44 we obtain the superficial area, which will be 616 square feet of copper sheet, each of which, as I have said, weighs three ounces, so that, multiplying 616 by 3, we get 1,848 ounces, which will be the weight of all the copper required to construct this ball, that is, 154 pounds.

Let us see now if the air contained in this vessel weighs more than 154 pounds, because, if so, if we exhaust the air, we leave the vessel lighter than air, and as much as it is the lighter so much more weight will it be able to carry and lift up into the air. To find the weight of the air contained therein we must find out how many cubic feet it contains, each of which, as has been shown, weighs an ounce and a half. To do this Archimedes again shows us that it is necessary to multiply half the diameter, in this case seven feet, by the third part of the circumference, which is $205\frac{1}{3}$, which done, we obtain the capacity of the vessel, which is $1{,}437\frac{1}{3}$, and as every cubic foot of air weighs one-and-a-half ounces the weight of the whole air contained in the vessel will be $2{,}155\frac{2}{3}$ ounces, equal to 179 pounds $7\frac{2}{3}$ ounces. Having shown, as I intended, that the copper covering the vessel weighs only 154 pounds, which makes the vessel lighter than the air by 25 pounds $7\frac{2}{3}$ ounces, it is evident that on exhausting the air from it, not only will it ascend, but it will also be enabled to lift a weight of 25 pounds $7\frac{2}{3}$ ounces.

But so that it may be enabled to raise heavier weights and to lift men in the air, let us take double the quantity of copper, 1,232 square feet, equal to 308 pounds of

copper; with this double quantity of copper we could construct a vessel of not only double the capacity, but of four times the capacity of the first, for the reason shown by my fourth supposition. Consequently, the air contained in such a vessel will be 718 pounds $4\frac{2}{3}$ ounces, so that if the air be drawn out of the vessel it will be 410 pounds $4\frac{2}{3}$ ounces lighter than the same volume of air, and, consequently, will be enabled to lift three men, or at least two, should they weigh more than eight pesi* each.

It is thus manifest that the larger the ball or vessel is made, the thicker and more solid can the sheets of copper be made, because although the weight will increase, the capacity of the vessel will increase to a greater extent and with it the weight of the air therein, so that it will always be able to lift a heavier weight.

From this it can be easily seen how it is possible to construct a machine which, fashioned like unto a ship, will float on the air (see Plate, Fig. 4). Let us build four globes, each of which is capable of lifting two or three men as described above, and is exhausted of air in the manner set out above (the globes are shown in Fig. 4 and marked A.B.C.D.). These are connected together by four ties as shown in the figure. Then construct a wooden car EF fashioned like a boat, with its masts and sails and oars, and with four ropes of equal length; attach the four spheres after having exhausted the air therein, but keeping the vessel anchored to the earth so that it should not get away and fly off before the men have entered in the car; then release the cords gradually

* 1 peso = about 27 lbs.—EDS.

and all together, so that the ship may lift itself up with the car, carrying with it many men, more or less, according to the lifting power. The passengers may use the sails and oars to travel with great speed to any place at will, even over the highest mountains.

But whilst I write down these matters I smile unto myself, realising that seemingly it sounds like unto a fable no less strange or incredible than those mad fantasies that issued from the fertile brain of Lucian. Yet, on the other side, I clearly discern that I have not erred in any of my proofs, especially as I have conferred on these matters with many sage and well-instructed persons who have not been able to find any errors in my discourses, having only expressed a desire to have a visible proof by one of these spheres which would, of itself, ascend in the air. Which thing I would willingly have done before publishing these my inventions, had not my vows of poverty prevented my expending 100 ducats, which sum at least would be required to satisfy so laudable a curiosity. Therefore I pray those readers of my book who may be curious to try my experiments, to acquaint me if they succeed, or if any errors committed in construction should prevent a successful issue, as no doubt I could show them how to correct any such errors. To encourage everyone to proceed on to the proof I will here smooth away some of the difficulties that may ordinarily present themselves in the practical working out of my invention.

Firstly: It may be found difficult to exhaust the sphere in the manner already described, which requires the globe A to be reversed so that the tube B C is underneath, which certainly could not be done without great

Hydrogen gas applied to Lana's project

(*Frontispiece to reprint of 6th Chap. of the "Prodromo" published at Rome in* 1784)

difficulty except with the aid of machinery, owing to the great size and weight of the vessel, being full of water. But this can be done in such a manner as not to require the vessel to be moved (Fig. 5), by placing it at a height of at least 47 palmi and connecting to its neck on the underside the tube of 47 palmi in length, which should be closed at its lower end C; then fill with water the vessel A and the whole of the tube by means of another opening D on the top; when full close the opening D with a screw or a tap; if then it is wished to empty the same, it is only necessary to open the lower end C of the tube immersed in water so the water can come out, but without allowing the air to enter. When emptied close the tap at the neck of the vessel and remove the tube, so we have a vessel which, even though it be not entirely exhausted of air, which point we will not here argue, will, at any rate, now weigh less by so many times an ounce and a half as there were cubic feet of water contained therein, which is sufficient for my purpose and has already been proven by experiment, as stated above. It is only necessary to use great care to ensure that the taps closing the vessel be made to fit very exactly, so that no air can enter through them.

Secondly: Difficulties may be experienced owing to the thinness of the vessel, because the great pressure of the outer air trying to force its way in to prevent there being a vacuum or, at any rate, an extreme rarefaction, would compress the vessel, and if not break it, at least flatten it.

To this, I reply, that it might so occur if the vessel were not round, but being spherical the outer air could only compress it equally on all sides, so that it would

rather strengthen it than break it, which has been shown by experiments with glass vessels, which, even if made of thick, strong glass, break into a thousand pieces unless round in shape, whereas round vessels of glass, although very thin, do not break; nor is it necessary that they should be perfectly round, but it suffices if they do not depart very much from a true sphere.

Thirdly: In constructing the copper globes they could be built up from two halves and then connected by the usual process of soldering, or even built up of many parts and connected in the same way, in doing which there is not much difficulty.

Fourthly: Some difficulty may be experienced as to the height to which the vessel may ascend, because if it were to ascend above the air, which is commonly reckoned to have a height of fifty miles more or less,* as we shall see further on, it would follow that men would not be able to breathe.

To which I would reply that the higher one ascends in the air so the more rarefied and lighter it is; therefore there will be a certain height which the vessel may reach, but beyond which it will not be able to rise, because the air above will be lighter and unable to sustain it, so that it will stop at a point where the density of air will be so light as to equal the weight of the whole machine and the persons thereon. In order

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* As the density of the air diminishes constantly with the altitude, it is impossible to speak of a defined "boundary" of the atmosphere. According to the latest researches, the atmosphere proper extends to 45 miles, or 240,000 ft. vertically, but traces of air are certainly present at a height of 200 miles and over. It may further be remarked that at the altitude of 45 miles the density of the air is $\frac{1}{10000}$th of that at sea-level.—EDS.

that it should not ascend too high, it will be well to add a greater or smaller weight, according to the height it is required to rise, but if even then it should continue to rise too high, that could easily be remedied by opening the taps, thus allowing a certain amount of air to enter the spheres so that, losing some of their lightness, they will descend and with them the ship; and if, on the contrary, it will not ascend as high as required, it could be made to rise by lightening it of any weight it was carrying. Similarly, wishing to descend to earth, it will only be necessary to open the taps so that the air entering slowly may cause the globes to lose their lightness and gradually descend until they bring the ship to earth.

Fifthly : Some may object that the ship could not be propelled by oars, seeing that they propel a ship through the water from the fact that the water offers resistance to the oars, whereas the air does not offer such a resistance.

To this I rejoin that, although air does not resist the thrust of the oars to such an extent as water, being lighter and more subtle, yet it offers an appreciable resistance and such as is sufficient to propel the ship; for the resistance of the air to the oars is exactly in the same proportion as its resistance to the motion of the ship, so that, although it offers little resistance to the oars, it will enable the ship to travel easily, also it will be rarely necessary to use the oars, as once up in the air there will be always a wind which, even if very feeble, will be sufficient to move it along with great speed; and if it were contrary to our intended course, I will give instructions elsewhere how to place the mast

of the ship in such a manner as to enable it to travel by any wind, not only in the air, but also on the water.

Sixthly : Much greater is the difficulty of preventing the ship from being driven at too great a speed by a strong wind, whereby it runs the risk of hurling itself against the mountains, which are the rocks of the aerial oceans, and be wrecked or upset, but, as to the latter possibility, I contend it would be very difficult for the wind to upset the whole weight of the machine with many men standing on it. They would always counterbalance the lightness of the globes, so that the latter would always remain above the ship, neither could ever the ship be driven above them, nor could the ship fall to the ground if no air be allowed to enter the globes, nor can there be any peril of falling overboard and being drowned as at sea, as holding on to the ropes or to the woodwork the men would be secure. As to the first objection I confess that our aerial ship might run great perils, but not more than the ships on the seas are liable, because, as in their case, so could we be furnished with anchors, which would easily grapple to the trees. Besides, although our aerial ocean has no shores, it has this advantage, that there is no necessity for ports of refuge for the airships, they being able every time they are in danger to descend from the high air and land on the ground.

Other difficulties I do not foresee that could prevail against this invention, save one only, which to me seems the greatest of them all, and that is that God would never surely allow such a machine to be successful, since it would create many disturbances in the civil and political governments of mankind.

Where is the man who can fail to see that no city would be proof against surprise, as the ship could at any time be steered over its squares, or even over the courtyards of dwelling-houses, and brought to earth for the landing of its crew? And in the case of ships that sail the seas, by allowing the aerial ship to descend from the high air to the level of their sails, their cordage could be cut; or even without descending so low iron weights could be hurled to wreck the ships and kill their crews, or they could be set on fire by fireballs and bombs; not ships alone, but houses, fortresses, and cities could be thus destroyed, with the certainty that the airship could come to no harm as the missiles could be hurled from a vast height.

GLIDING

BY

PERCY S. PILCHER

PERCY SINCLAIR PILCHER

Aeronautical Classics — **No. 5**

GLIDING

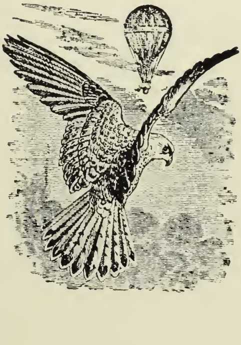
BY

PERCY S. PILCHER

TO WHICH IS ADDED

THE AERONAUTICAL WORK OF

JOHN STRINGFELLOW



PRINTED AND PUBLISHED FOR

THE AËRONAUTICAL SOCIETY OF GREAT BRITAIN,

By KING, SELL & OLDING, LTD., 27, Chancery Lane, W.C.

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1910

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Edited for the Council of the Aëronautical Society of Great Britain

by

T. O'B. HUBBARD & J. H. LEDEBOER

MEMOIR

Otto Lilienthal once remarked: "It is easy to invent a flying-machine; more difficult to build one; to make it fly is everything." These words picture not inaptly the three stages in the history of flight. Even in the dark ages the invention of a flying-machine presented few difficulties to any ingenious mind that ventured to brave the forces of theology, as the long succession of projects and designs for aerial conquest amply proves. Nor were the obstacles that beset the path of the builder ever of so serious a nature as to jeopardise his chances of ultimate success. Admiration in full measure falls only to the due of the rare adventurous spirits who, combining the qualities that make for greatness in invention and construction, added thereto the courage, conviction and high endeavour that characterize the great practical pioneers.

Of these was Percy Sinclair Pilcher, born in January, 1866. Joining the "Britannia" at the age of thirteen, he completed six years' service in the Royal Navy, from which he retired in 1885 in order to devote himself to the profession of engineering.

After working through the shops—at Elder's Shipbuilding Yard, at Govan, near Glasgow—he attended London University, and in 1893 was appointed Assistant Lecturer in Naval Architecture and Marine Engineering at Glasgow University. A few years later, in 1896, he joined Hiram S. Maxim, with whose experimental work, subsequent to the failure of the large steam-driven aeroplane, he was closely associated. Shortly before his death he became a partner in the engineering firm of Wilson and Pilcher, who were to have undertaken the construction of his future machines and engines at their works at Westminster. Becoming a member of the Aëronautical Society in 1897, Pilcher was elected to the Council in November of the same year; and, in the two short years of his membership, succeeded in instilling into the debates and the work of the Society a portion of the enthusiasm and energy that he himself so signally possessed.

The problems of flight fascinated him from an early age, but it was not until the first months of the year 1895 that an opportunity was vouchsafed him of putting his ideas to the momentous test of practice at Glasgow. Here, in the intervals allowed by his duties at the University, Pilcher built his first glider, the "Bat." At this time his only knowledge of the active work pursued by Lilienthal in Germany was derived from inadequate and inaccurate reports in the Press; the "Bat," therefore, was entirely the product of his own original conceptions. At the very outset of his experiments Pilcher was confronted with a serious difficulty: owing to his engagement at the University he was forced to carry out the work of construction of the

glider in the town, whereas the practical tests could only be made in the country, at a considerable distance. The machine, therefore, had to be built so as to be capable of being folded up to meet the requirements of transportation. This problem was successfully solved. Thus it is indeed noteworthy that Pilcher, Lilienthal, and Ader, the first three pioneers of practical dynamic flight, each succeeded in overcoming so serious an obstacle to efficiency before which their successors have hitherto uniformly failed.

The "Bat" was a monoplane, completed before June, 1895, when Pilcher visited Berlin, where he made several glides in Lilienthal's large biplane glider. The wings of the "Bat" formed a pronounced dihedral angle: the tips being raised 4 feet above the body. The spars forming the entering edges of the wings crossed each other in the centre and were lashed to opposite sides of the triangle that served as a mast for the stay-wires that guyed the wings. The four ribs of each wing, enclosed in pockets in the fabric, radiated fan-wise from the centre, and were each stayed by three steel piano-wires to the top of the triangular mast, and similarly to its base. These ribs were bolted down to the triangle at their roots, and could be easily folded back on to the body when the glider was not in use. A small fixed vertical surface was carried in the rear. The framework and ribs were made entirely of Riga pine; the surface fabric was nainsook. The area of the machine was 150 sq. ft.; its weight 45 lbs.; so that in flight, with Pilcher's weight (145 lbs.) added, it carried $1\frac{1}{3}$ lbs. per square foot.

The first glides were attempted in July, 1895, down

a grass-hill situated on the banks of the Clyde at Wallacetown Farm, near Cardross. Owing to the exaggerated dihedral angle of the wings and to the absence of any tail-surface save the small vertical one, these first experiments were attended with but little success. Pilcher would take up his position on the top of the hill, standing upright with his shoulders passed through the opening in the wings and, grasping the body members, run down the slope with the wings tilted at a negative angle until sufficient speed had been attained, when the wings would suddenly be tipped up so as to allow the glider to be carried off the ground. But defective balance always brought the machine to earth again within a few yards.

To remedy these defects the "Bat" was transformed: the wings were lowered until the tips were only 6 inches above the level of the body, and a horizontal tail-plane was added to the vertical one crosswise; this horizontal plane was movable, being capable of being tipped up, but the vertical plane remained fixed. The forward spars of the wings, now built of bamboo, were arched transversely. On September 12 the reconstructed "Bat" was tried for the first time, and with gratifying results. During the first glide, picked up by the rising head-wind, Pilcher rose to a height of 12 feet and remained in the air some 20 seconds; at a second attempt the glider was towed by a rope, rose to 20 feet, and landed safely after the space of nearly one minute. Many successful glides followed; growing experience gradually increased their length and improved the balance in the air. But, in landing, the wing-tips were apt, owing to their small clearance, to

come in contact with the ground, and many breakages resulted.

Accordingly, a second glider was built during the summer months of 1895, in which the wing-tips were designed to have a clearance of some 6 feet from the ground. This second glider, the "Beetle," differed considerably from the "Bat." The square-cut wings formed almost a continuous plane, rigidly fixed to the central body, which consisted of a shaped girder. These wings were built up of five transverse bamboo spars, with two shaped ribs running from fore to aft of each wing, and were stayed overhead to a couple of masts. The tail, consisting of two discs placed cross-wise (the horizontal one alone being movable), was carried high up in the rear. With the exception of the wing-spars, the whole framework was built of white pine. The wings in this machine were actually on a higher level than the operator's head; the centre of gravity was, consequently, very low, a fact which, according to Pilcher's own account, made the glider very difficult to handle. Moreover, the weight of the "Beetle," 80 lbs., was considerable: the body had been very solidly built to enable it to carry the engine which Pilcher was then contemplating; so that the glider carried some 225 lbs. with its area of 170 sq. ft.—too great a mass for a single man to handle with comfort.

This summer, of 1895, had been one of very light winds; during several days, in fact, the calm air had prevented him from making any glides. Influenced, no doubt, by these conditions, Pilcher built his third glider of far greater proportions. This machine, the "Gull," was completed at Glasgow in the early months of 1896.

In general it was a reversion to the type of the "Bat" save that the wings were arched downwards. It had 300 sq. ft. of area, weighed 55 lbs., and only carried $\frac{2}{3}$ lb. per square foot. It was tried during the ensuing summer months, but, owing to its large area rendering it suitable for practice only in the calmest weather, was severely damaged on several occasions when flown in a stiff breeze.

The fourth glider, the "Hawk," was also built early in 1896, at Eynsford, in Kent.

The "Hawk" formed a great advance on its three predecessors; indeed, in many respects, it was a thoroughly up-to-date, exceedingly well-built glider. From an engineering point-of-view, taking into account the serious difficulties arising from such requirements as collapsibility, this glider was undoubtedly a sound machine. With the single exception of the two main transverse beams, it was built throughout of bamboo, admittedly the most difficult material for building up a satisfactory framework. The wings were attached to two vertical masts, 7 ft. high, and 8 ft. apart, joined at their summits and their centres by two wooden beams. Each wing had nine bamboo ribs, radiating from its mast, which was situated at a distance of 2 ft. 6 inches from the forward edge of the wing. Each rib was rigidly stayed to the top of the mast by three tie-wires, and by a similar number to the bottom of the mast. By this means the curve of each wing was maintained uniformly. At their inner extremities these ribs were strung to the mast on rings so that, by loosening the attachment of the forward edge of the wing to the body, the ribs folded backwards into a position which rendered

transport extremely convenient. The tail was formed by a triangular horizontal surface, to which was affixed a triangular vertical surface; and was carried from the body on a high bamboo member. It was also stayed from the masts by means of steel wires, but only on its upper surface*; in consequence, when acted on by the pressure of the air, the tail could only be forced upwards, and not downwards; by this arrangement the glider, when in flight, was prevented from adopting a dangerous dipping angle. The body consisted of a narrow aperture formed between the two wings by two bamboo rods bent into a "fair" shape. The operator took up his position by passing his head and shoulders through the body aperture, and resting his fore-arms on the longitudinal body members. Supports were provided for the arm-pits. It will be seen that, owing to this arrangement, the head, shoulders, and greater part of the chest projected above the wings; the centre of gravity was consequently only slightly below their level. Underneath the body were attached two bamboo rods fitted with wheels suspended on steel springs. When on the ground the weight of the glider rested on this elementary chassis, which also took the first impact of landing.

The following were the chief dimensions: Span 23 ft. 4 in.; chord 8 ft. 4 in.; length over all 18 ft. 6 in.; area of main plane 180 sq. ft.; camber 5 in. (situated 2 ft. 6 in. behind the forward edge); area of horizontal tail plane 12 sq. ft.; weight of glider 50 lb.; weight in flight 195 lb.; loading, a fraction over 1 lb. per sq. ft.

* The snapping of one of these guy-wires, causing the collapse of the tail support, brought about Pilcher's fatal accident.

The balance and steering of the "Hawk," apart from the slight degree of automatic stability afforded by the tail, were effected, as before, by altering the position of the operator's body; and, although this method appears to modern eyes crude in the extreme, it must be admitted that Pilcher acquired such dexterity in handling his machine by these means that he never met with a serious accident until the day of his death.

On this last glider, the "Hawk," Pilcher made some dozen glides at Eynsford during the summer months of 1896, and showed the value of his growing experience by the increased length of his glides and the ease wherewith he handled the machine in the air and in landing. But, the claims of business growing ever more insistent, opportunities for practice during this summer were limited. While postponing further experiments to the following spring, Pilcher was already occupied with the preparation of his plans for fitting a small engine and propeller to his latest glider; these plans would, in fact, have been carried out even earlier had there not arisen the usual difficulty that no engine of sufficient lightness could be found. An engine said to give one horse-power and to weigh but 15 lbs. was, it is true, reported to be in existence in America; but every endeavour to trace it was effectually baffled.

On January 21, 1897, Pilcher gave a lecture in Dublin before the Military Society of Ireland, presided over by Major-General Viscount Frankfort de Montmorency, commanding the troops in Dublin. This lecture gave, for the first time, a complete account of his own gliding experiments, and of those carried out by Lilienthal, and

ended with a description of the work recently accomplished by Hiram Maxim with whom Pilcher was now associated. This lecture is reprinted in the following pages in its entirety, save for the concluding portion relating to Maxim's work which is already familiar to every student of aeronautics.*

During the spring of the following year the gliding experiments were resumed at Eynsford with the "Hawk." Unsuccessful in his efforts to secure a suitable engine, and unwilling to depend entirely on the rare chance of finding the favourable wind essential for his former method of practice—by running down a slope—Pilcher compromised by having his glider towed by a line passing over a pulley. This pulley was situated on the top of a hill; Pilcher took up his position on the crest of a neighbouring hill, and thus succeeded in making several long glides. Perhaps the best of these was accomplished on June 19 of this year, when he crossed the intervening valley at a great height and alighted, after a perfectly balanced glide of over 250 yards in length, on the opposite hill. The "rope" used on these occasions was a thin fishing line "which one could break with one's hands," and the pull on it, during flight, did not exceed 30 lbs.

In the absence of the American engine, Pilcher was now resolved to proceed forthwith to build a suitable engine himself. Observation had shown that the "Hawk," carrying a total weight of 190 lbs., glided at a speed of 20 to 25 miles per hour, the pull on the line

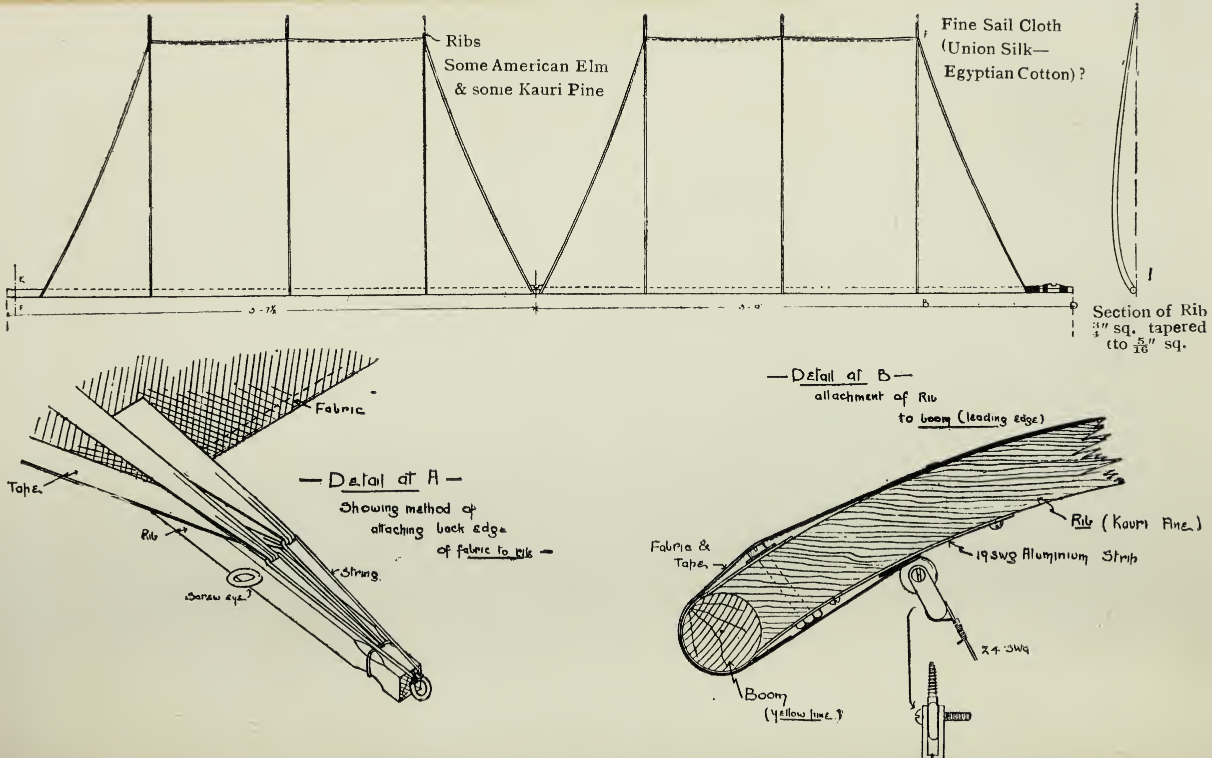
* "Artificial and Natural Flight," by Sir Hiram Maxim; London, 1909.

being from 20 to 30 lbs. Herefrom Pilcher concluded that from 2 to 3 horse-power would suffice for the maintenance of horizontal flight once the machine was in the air. Allowing for the additional weight of engine and propeller, and taking into account the latter's inefficiency, a 4-H.P. engine was deemed sufficient. The weight of this oil engine was estimated at 40 lbs.; the propeller, 5 ft. in diameter, with a 4-ft. pitch, built of yellow pine covered with light canvas, weighed but $3\frac{1}{2}$ lbs. The driving mechanism was to be installed in the "Hawk" in the following manner: the engine, fitted in front of the operator, was to actuate, by means of an overhead shaft, the propeller situated to the rear of the wings. The whole of the year 1898 was occupied with the construction of the engine—a slow and tedious process.

At the beginning of this year Pilcher had formed, with Walter G. Wilson, the firm of Wilson and Pilcher, Ltd., for working out inventions and patented ideas. At first the firm only had some small shops in Clerkenwell, but as business increased rapidly, the works were moved to Great Peter Street, Westminster, where the construction of the oil engine was begun.

About this time, furthermore, Pilcher was actively endeavouring to found a company in order to carry out future experiments, and for this had obtained the support of Dr. Elgar, Mr. Yarrow, the famous shipbuilder, Professor Biles, of Glasgow, and the late Professor Fitzgerald, of Dublin. Writing to the latter at the end of 1898, Pilcher remarks:

> "During the last year I was not able to do anything with the flying work, as we were so very busy getting our new



PILCHER'S TRIPLANE

business into going order; but the summer before, when I was able to devote some time to it, the results we obtained were most encouraging, and consequently we are most anxious not to let the experiments drop altogether. In America experiments are continually being made, and it would be heartrending not to try and keep one's place in the work that is being done."

Then, early in 1899, there happened an event that, but for his untimely death, would undoubtedly have influenced the entire future course of Pilcher's experiments. On May 26, Lawrence Hargrave read before the Aëronautical Society a paper on his newly-discovered "soaring kites." Pilcher, who was in the chair at this meeting and led the subsequent discussion most ably, was deeply interested in Hargrave's account and afterwards took with him the two soaring kites brought over by Mr. Hargrave and by him presented to the Society.

Many experiments were carried out with these soaring kites by Pilcher during the ensuing months, and there is some reason for believing that their principle was incorporated—to some extent, at least—in a new machine which was built by Wilson and Pilcher during the course of 1898 and 1899. Unfortunately only a few fragments of this machine have been preserved, from which it is impossible to re-constitute the glider. The only certainty is that it was a triplane. Some of its constructional features are indicated in the accompanying drawings, executed by Messrs. T. W. K. Clarke and Co.*

* This triplane, the "Hawk," and a Lilienthal glider purchased by Pilcher were presented after his death to the Aëronautical Society. The two latter machines are still in the possession of the Society and have several times been on exhibition.

But death overtook him before an opportunity had arisen to try this new machine. While on a visit to Lord Braye, at Stanford Hall, Market Harborough, Pilcher consented to give a demonstration of gliding flight on the afternoon of Saturday, September 30, 1899. Both the "Hawk" and the new superposed-plane machine were brought out, but, in view of the unfavourable weather—it had been raining heavily, the ground was drenched and the gliders sodden—it was resolved to postpone the trial of the new machine. The "Hawk" on this occasion was intended to rise from a level field, towed by a light line passing over a tackle drawn by two horses. On the first trial the machine rose easily after a short run, but when well clear of the ground the tow-line snapped and the glider, liberated, descended gently to the ground. Although the machine was weighted down by its sodden condition, another trial was resolved upon: the glider rose easily from the ground and was soaring at a height of about 30 ft. when one of the guy-wires of the tail broke, the tail collapsed, and the machine fell headlong to the ground, turning over in its fall. Pilcher, unconscious, was freed from the wreckage; at first sight his condition seemed to give hope of recovery, but, after lingering on through Sunday, he died, without recovering consciousness, early in the morning of Monday, October 2, 1899.

His services rendered to the cause of human flight stand out clearly from the foregoing brief record of his work, and in truth require no further words of appreciation. On the whole, he may fitly be assigned a place by the side of Otto Lilienthal. For these two, if we except the somewhat mysterious figure of Le Bris, were

the first real flying men. The great German perhaps approached the matter in the more scientific spirit, and in so far, no doubt, his work is the more lasting. Pilcher, too, had the undoubted advantage of treading in Lilienthal's footsteps; though, be it observed, his work was original enough, witness the completion of the "Bat," before the visit to Berlin, with the express object of preserving any originality of idea that might have gone to its construction. In common with Lilienthal, Pilcher persevered to the end in balancing his machines by correcting the position of the centre of gravity—by body movements—in flight. But apart from this single defect, his gliders were thoroughly modern; nor can there be much doubt, to judge from his correct appreciation of the functions of the tail, that Pilcher would have adopted the movable horizontal plane for this purpose, had time permitted.

In one respect certainly he anticipated modern practice: the "Hawk" was the first machine to be fitted with wheels, provided with shock-absorbers, whereon to roll over the ground in its initial run. Two other points, on which Pilcher strongly insisted, are worthy of repetition: the great advantage possessed by the small machine over the larger one, in respect of the serious difficulties of construction and disproportionate weight of the latter; and the great skill required to balance too large a structure. Further, he laid great stress on the evil effects of a low centre of gravity; his tendency to place his weight as high as possible may, in fact, be clearly noted by comparing the "Bat" or the "Beetle" with the "Hawk."

When all is said, the final impression that remains

from a consideration of his work is one of deep admiration for the originality, perseverance, and enthusiasm of this young engineer, whose life was sacrificed in his 34th year, but who, in the four short years that formed the full period of his activity, accomplished pioneer work that will render his name famous while the history of aerial navigation endures.

GLIDING

THE history of experiments with flying machines has been up to the present more or less a history of disasters. There has often been a certain amount of success, but in almost all cases where any success has been attained there has been a capsize, or a fall, or some accident, which has brought the experiments to a close.

The first man of whom we know as having attempted flight, after the days of mythology, was Roger Bacon, who, in about 1250, is said to have made a soaring machine; but he lost his longitudinal balance, having jumped from an eminence, and broke his machine and his legs*. He was shortly afterwards imprisoned for witchcraft.

J. B. Dante, a mathematician, of Perugia, Italy, is said to have sailed across a lake on wings at the end of the 14th century. Again, starting from a tower, he is said to have balanced himself for a long time in the air; but the machine broke in the air, and he fell on to the top of a church and broke his leg.

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* Pilcher appears to confuse Bacon with Oliver of Malmesbury.—EDS.

During the next four hundred years a good many experiments were made by various people with wings, but through want of elementary knowledge of the subject, and want of good materials to work with, none, apparently, had much success.

In 1854 Captain Le Bris, a French sailor, constructed what he called an artificial albatross. The apparatus was 50 feet wide, $13\frac{1}{2}$ feet long, and its sail area was 215 square feet; it weighed 92 lbs. This was really a simple soaring machine; but instead of moving his weight about in the machine to balance it, Le Bris had arrangements to alter the inclination of the wings by levers which he held in his hands, and he altered the inclination of the tail by a mechanism which he worked with his feet. His first experiment was made with the machine tied to the top of a cart by means of a slip rope, so that Le Bris, who was in the machine, could detach it from the cart just when he wished. The cart was driven along a road facing a ten-mile wind. When the pace was sufficient, Le Bris pulled at the slip rope which let the machine go, but somehow or other the rope had got round the carter, and Le Bris was taken up into the air, with the carter hanging on to the end of the rope underneath the machine.. The machine is said to have gone up 300 feet into the air, and cleared about 600 feet in distance, when Le Bris, the machine, and the carter came down unharmed. In the next trial, in which the carter did not go up, one wing got broken. Le Bris next tried the apparatus by dropping it from a crane at the edge of a quarry, 100 feet drop. He lost his balance, the machine was broken completely, and Le Bris broke his leg.

Thirteen years later a public subscription enabled Le Bris to build another machine. More experiments were made, but the apparatus got broken up on a gusty day, and Le Bris could not get enough money to go on with his experiments.

Since then there have been many experiments made with soaring machines, but much the most interesting are those of Herr Lilienthal, an engine builder, of Berlin, who, most unfortunately, got killed a few months ago* by losing his balance when in the air.

Lilienthal had been experimenting with models practically all his life, and spending all his spare time and money on them, until in the summer of 1891 he began experimenting with his first soaring machine, built to carry himself. It had about 100 square feet of surface.

Since then his machines have been much altered. In the spring of 1895, I saw him experiment with a machine of 150 square feet, weighing 56 lbs. These machines are roughly made, almost entirely of peeled willow sticks, covered with cotton shirting.

Illustration 1 shows one of these machines. A man is holding a machine in the position it would be when flying, and his forearms pass through padded tubes, and his hands hold a cross bar. This is the only way in which he is attached to the machine, so that he can, when standing on the ground, place the machine at any angle to the wind, and when supported by the air he can move his body a considerable distance forwards or backwards or sideways so as to preserve his balance and guide the machine. Professor Fitzgerald has one of these machines in Dublin.

* August 10, 1896.

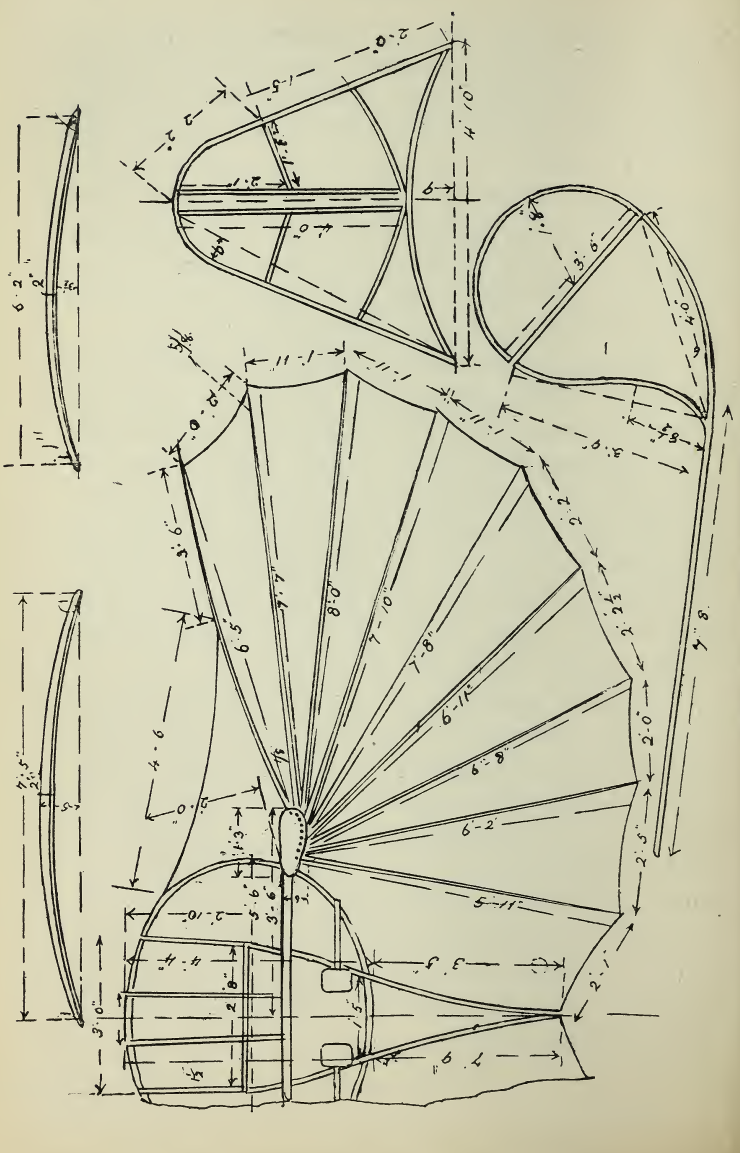

Fig. 1a.—Lilienthal's Monoplane Glider
Scale Drawings.

To fold up, the front of the sail is unhooked from the front of the machine; all the spokes in the sail revolve round, and thus the machine shuts up quite small.

At first Lilienthal used to experiment by jumping off a spring-board, with a good run. Then he took to practising on some hills close to Berlin. In the summer of 1892 he built a flat-roofed hut on the summit of a hill, from the top of which he used to jump, trying, of course, to soar as far as possible before landing.

Illustration 2 shows the machine in a critical position. He has got the machine too much up in front; it has lost its forward motion, and consequently his legs are thrown very far forward to get the centre of gravity forward, so as to incline the machine down in front that it may shoot on again. One of the great dangers with a soaring machine is losing forward speed, inclining the machine too much down in front, and coming down head-first. Lilienthal was the first to introduce the system of handling a machine in the air merely by moving his weight about in the machine; he always rested only on his elbows or on his elbows and shoulders. There are two little pads with which his shoulders come in contact, when his arms are almost straight, to prevent him from tumbling through and breaking his arms; these are shown in illustration 1.

He added these pads because once, having thrown his weight very far back, he was unable to pull himself up again. He described his descent to me thus: "I was blown about exactly like a sheet of paper when it is caught by the wind. At first I saw only blue sky, and then I saw only green grass, and I thought now it is all over with me." He broke his wrist.

This method of support, although it appears uncomfortable, is not really so bad as it seems, and one can soon get accustomed to it. It allows great freedom in moving one's weight about, and gives one an excellent command of the machine when standing on the ground. It has often been suggested that it would be a good plan to have a pair of stirrups to fit one's feet into while in flight, to have a net to sit in, or some such device to relieve the weight on the arms; but so far the length of flight has never been so long as to make such a thing necessary, and anything of this kind would be an encumbrance, and would hinder free movement, fidget one, and keep one from slipping out of the machine quickly in case of accident.

In 1892 a canal was being cut, close to where Lilienthal lived, in the suburbs of Berlin, and with the surplus earth Lilienthal had a special hill thrown up to fly from. The country round is as flat as the sea, and there is not a house or tree near it to make the wind unsteady, so that this was an ideal practising ground; for practising on natural hills is generally rendered very difficult by shifty and gusty winds.

Illustration 3 shows this hill. It is 50 feet high, and conical. Inside the hill there is a cave for the machines to be kept in. Here he is shown sailing down the slope.

When Lilienthal made a good flight he used to land 300 feet from the centre of the hill, having come down at an angle of 1 in 6; but his best flights have been at an angle of about 1 in 10.

If it is calm, one must run a few steps down the hill, holding the machine as far back on oneself as possible, when the air will gradually support one, and one slides

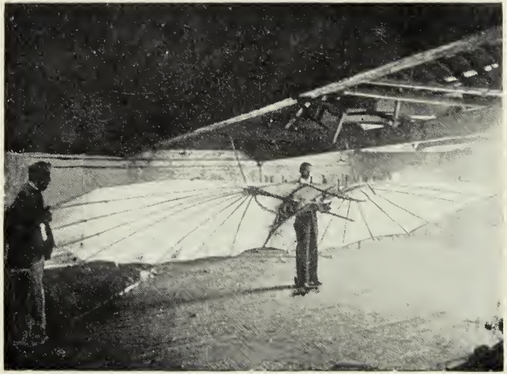

Fig. 1.—Lilienthal's monoplane glider

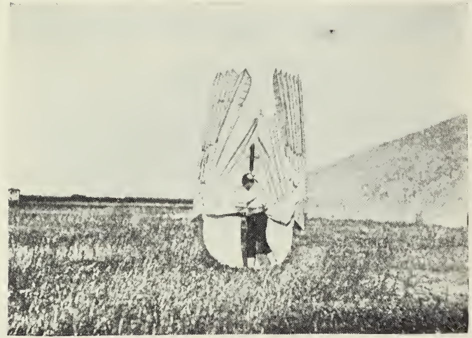

Fig. 2a.—O. Lilienthal with his glider folded up after a glide from the hill

Fig. 2.—In a critical position

Fig. 3.—Gliding down the hill


Fig. 4.—Lilienthal's biplane glider soaring

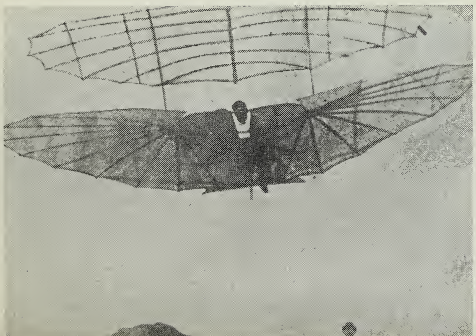
Fig. 5.—A near view of Fig. 4

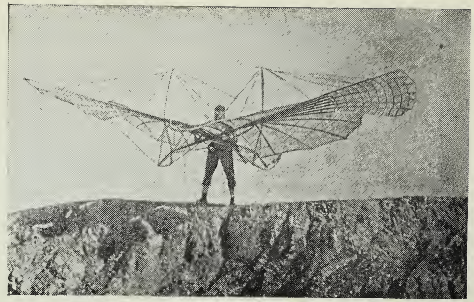
Fig. 6.—Lilienthal's power-driven machine


Fig. 7.—The "Bat"

off the hill into the air. If there is any wind one should face it at starting; to try and start with a side wind is most unpleasant. It is possible after a great deal of practice to turn in the air, and fairly quickly. This is accomplished by throwing one's weight to one side, and thus lowering the machine on that side towards which one wants to turn. Birds do this same thing—crows and gulls show it very clearly. Last year Lilienthal chiefly experimented with double-surface machines. These were very much like the old machines with awnings spread above them.

In illustrations 4 and 5, he has been picked up above the top of the hill by a sudden gust of wind striking him; he, being at rest and possessing considerable weight, was able to be lifted several seconds before the wind overcame his inertia. I myself have often been lifted in this same manner. It is necessary to get well forward in the machine at the right instant, so that one may shoot forward against the wind, and not be carried away with it. I have been picked up fully 12 feet from the ground, and put down again on exactly the same spot.

The object of making these double-surface machines was to get more surface without increasing the length and width of the machine. This, of course, it does; but I personally object to any machine in which the wing surface is high above the weight. I consider that it makes the machine very difficult to handle in bad weather, as a puff of wind striking the surface, high above one, has a great tendency to heel the machine over. The machine shown in illustration 4 had about 250 square feet of surface.

Herr Lilienthal kindly allowed me to sail down his

hill in one of these double-surface machines last June. With the great facility afforded by his conical hill the machine was handy enough; but I am afraid I should not be able to manage one at all in the squally districts I have had to practise in over here.

Herr Lilienthal came to grief through deserting his old method of balancing. In order to control his tipping movements more rapidly he attached a line from his horizontal rudder to his head, so that when he moved his head forward it would lift the rudder, and tip the machine up in front, and *vice versâ.* He was practising this on some natural hills outside Berlin, and he apparently got muddled with the two motions, and, in trying to regain forward speed after he had, through a lull in the wind, come to rest in the air, let the machine get too far down in front, came down head first and was killed.

The object of experimenting with soaring machines is to enable one to have practice in starting and alighting and controlling a machine in the air. They cannot possibly float horizontally in the air for any length of time, but to keep going must necessarily lose in elevation. They are excellent schooling machines, and that is all they are meant to be, until power, in the shape of an engine working a screw propeller, or an engine working wings to drive the machine forward, is added; then a person who is used to sailing down a hill with a simple soaring machine will be able to fly with comparative safety. One can best compare them to bicycles having no cranks, but on which one could learn to balance by coming down an incline.

Illustration 6 shows a machine which Lilienthal made

in the summer of 1895, in which more than simple soaring is attempted. The extremities of the wings are made to flap, and constructed so that flapping will drive the machine ahead. The power was derived from a cylinder of compressed carbonic acid gas, and when Lilienthal pressed a valve with the thumb of his right hand, a piston in a working cylinder made a stroke, and caused the wings to give one flap. With this type of engine he was only able to carry enough power to last for about half a minute. He had several minor accidents with the mechanism of the machine which delayed him, so that he made no real horizontal flights with it.

MY OWN EXPERIMENTS

I began to make my first soaring machine at the beginning of 1895. I had seen photographs of Lilienthal's apparatus, but I purposely made my own before going over to Berlin to see his, so as to get the greatest advantage from any original ideas I might have; but I was not able to make my first trials with this machine till June, 1895, after I had seen Lilienthal fly. Illustration 7 shows my first machine tipped up to show the details. The object of the triangle is to obtain points from which to bring the wires which stiffen the sails. There were three wires from the top of the triangle to each rib in the sails, and three wires from one of the lower corners of the triangle to each rib on the same side. Please note that there is a vertical, but no horizontal, rudder.

I am going through my own course of experiments somewhat in detail, because it has been instructive.

Illustrations 8 and 9 show the next development. There is a horizontal rudder as well as a large vertical rudder. Without the horizontal rudder I was able to do nothing—it was not until I had put on the horizontal rudder that I was able to leave the ground at all. Lilienthal told me that a horizontal rudder was absolutely necessary. I would not believe him, but found out that he was quite correct. These two "model gliders" show the point very clearly. They are quite similar, except that the one has two surfaces, the second surface acting as a rudder, and the other has only one surface. When I throw the single-surface one you will see that it will only go straight for a yard or two, then keep on turning head over heels, whereas the double-surface one will probably sail perfectly well.

In the illustration please note that the wings are very much turned up at the points. I did this because I believed that it would facilitate transverse balance, on the principle that a piece of paper bent into a **V** shape will always come down edge first, and a cone will, if dropped, always come down on its point. If stability is got by having the weight very low, as in a parachute, there will be a big oscillation.* It must also be remembered that a man soaring, if he meets with an accident, gets a comparatively very much worse fall than a smaller

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* These facts were illustrated by Mr. Pilcher with a paper cone which, when dropped from the roof, came down quite steadily, whereas a small parachute, made of linen and weighted with lead, showed a great deal of oscillation.—EDS.

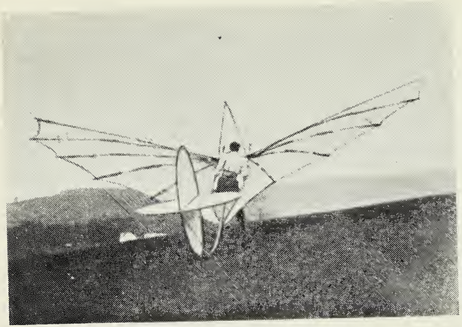


Fig. 8.—The "Bat" with a tail

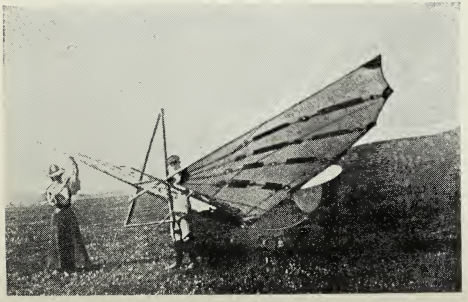


Fig. 9.—The "Bat"; side view

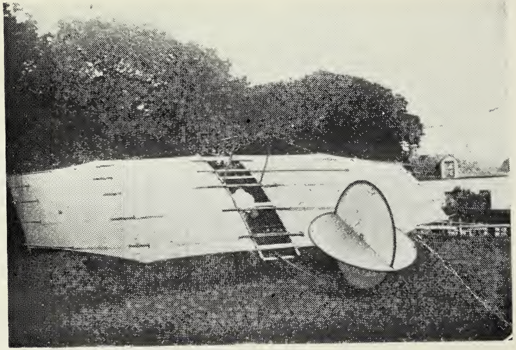


Fig. 10.—The "Beetle"; rear view

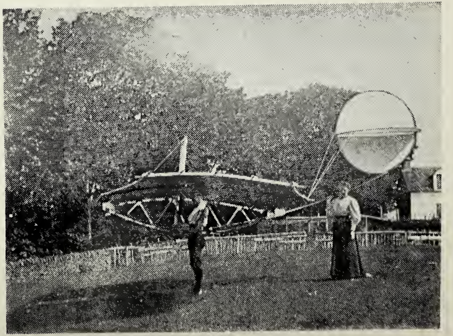
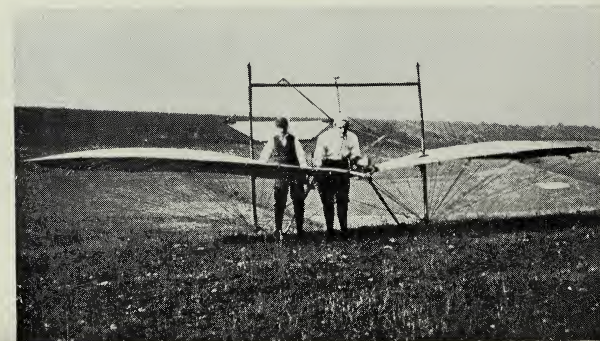


Fig. 11.—The "Beetle"; side view

Fig. 12.–The "Bat" modified.

Fig. 14.–The "Gull"



object. An insect can get knocked down by the wind, and remain uninjured.*

The upturned wings were all very well if there was no wind, or if the wind was steady; but if the wind shifted slightly sideways, and came on to one side of the machine, it would tend to raise the windward wing and depress the lee one, and capsize me sideways, which always meant a breakage in the machine.

To obviate this I built a second machine quite flat transversely, with the whole surface considerably raised so as to keep the wing tips a good distance off the ground (illustrations 10 and 11). This machine was, unfortunately, very heavy, and the wing surface being placed considerably above me, I had very little control over it. A sudden puff of wind would carry the machine backwards, leaving me, because of my weight, as it were behind, and it was only by slipping out of the machine when it was above my head that I several times avoided going head over heels backwards with it.

Illustration 12 shows the next alteration in the first machine. The wing tips have been considerably lowered, and with this machine in this condition I obtained by far my best results at Cardross, on the Clyde, where I experimented in the summer of 1895. The illustration shows the machine floating in the air. When being held at the front, any of the machines can be held in the wind quite easily with one finger, although they weigh from 50 to 80 lbs.

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*To illustrate this point two cards of equal area but one weighing four times as much as the other, were dropped from the roof, the heavier one falling in exactly half the time that the lighter one took to drop.—EDS.

I had better mention the names these machines were always called by. The first one was the "Bat," the second flat one was called the "Beetle," because it looked like a beetle; my fourth machine is the "Hawk."

Illustration 13 shows the "Bat" flying. The wing surface of the "Bat" is about 150 square feet; that of the "Hawk" is 170.

Illustration 14 shows my third machine, the "Gull," with 300 square feet. I got it broken up twice last year, and have not yet had time to rebuild it. It was intended for practice only on calm days; but I had not patience to wait for them, and took it out when there was practically no holding the large wing surface. The "Hawk," the machine with which I am practising now, is very like the "Gull," the curvatures being exactly similar.

The "Hawk" I built last winter. It weighs 50 lbs. I think this is the best system for building a soaring machine; it seems to be stiffer and lighter than any of the other methods. During the latter part of last summer* I had the machine out about ten times at Eynsford, in Kent. I have, unfortunately, had to be very busy about other things, and have not been able to spend much time in experimenting. Please remember this machine has been drenched several times, and several times I have landed in bushes, and once caught in a wire fence while going fast, and so she does not look so fresh as when she was first built.†

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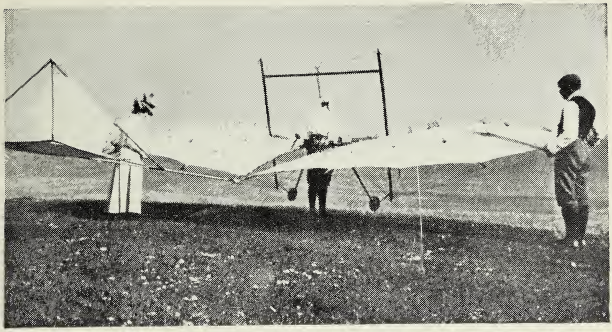
* The year referred to is 1896.

† The "Hawk" was exhibited in the room during the lecture, and its handling demonstrated by Mr. Pilcher. When landing the glider was tipped up, the weight being well back; when sailing fast the weight had to be well forward.—EDS.



Fig, 16—The "Hawk"; rear view

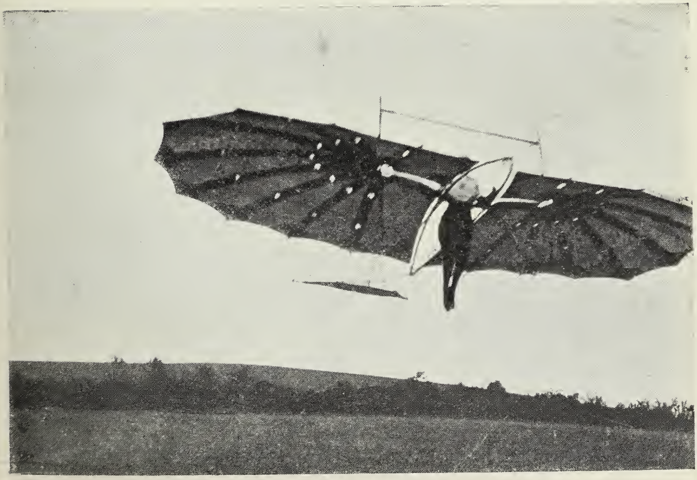


Fig. 17.—The "Hawk" in flight

Fig. 18.—P. S. Pilcher on the "Hawk"

Fig. 19.- The "Gull" with wings folded for transport

In this machine I have done away with the first rudder altogether. Whether this is an advantage or not I am not certain. The greatest distance I have cleared with this machine is about 100 yards—once with a slight side wind, once in a dead calm. Most unfortunately I have never had the machine out when it has been blowing up the best hill for experimenting at Eynsford, or I should be able to record much longer distances.

This is the first machine on which I have ever had any wheels. If I make a bad landing these two small wheels are able to take a great part of the jar, as behind the bamboo which supports them on each side there is a very stiff spiral spring.

The great thing to be learnt with these machines is to land properly. One must, before landing, get right back in the machine, so as to tip it well up in front, and so bring the machine to rest in the air instead of on the ground.

You will note that the horizontal rudder is made so that it can be lifted, but cannot be depressed. This seems to allow it to answer the purpose which is required of it, and saves it from getting broken if one tips the machine up a great deal, as is frequently necessary when coming to the ground.

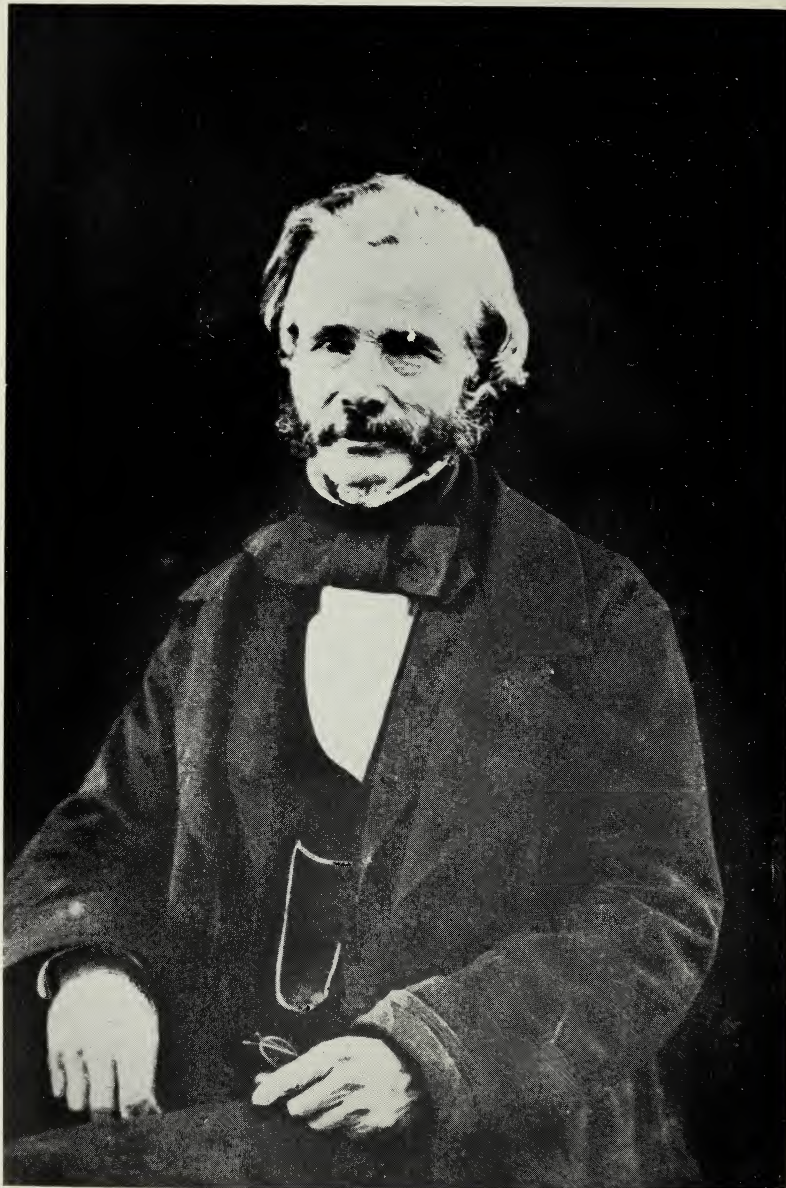
It is my intention this winter to make another machine very similar to this, but having a small oil engine situated just in front of me on the machine, with a shaft passing over my head, working a screw propeller of about 4 feet diameter, situated behind me. The machine will be started in exactly the same way as the soaring machines, by running down an incline, and when in the air the screw will be started to revolve, and in

this way I hope to be able to maintain horizontal flight. From soaring machine experiments, it appears that an expenditure of energy of about two H.P. per minute is necessary; I shall therefore use an engine of about four H.P., because of the inefficiency of the screw and other losses. The flying speed would be about 30 miles per hour.

THE AERONAUTICAL WORK

OF

JOHN STRINGFELLOW



JOHN STRINGFELLOW

THE AERONAUTICAL WORK

OF

JOHN STRINGFELLOW

WITH SOME ACCOUNT OF W. S. HENSON

JOHN STRINGFELLOW, the first man to make an engine-driven aeroplane which flew, was born on December 6th, 1799, at Attercliffe, near Sheffield, and at an early age was apprenticed to the lace trade in Nottingham. His father, William Stringfellow, had been noted for his mechanical ingenuity, which blossomed again with increased vigour in his son. About 1820, having gained considerable reputation as a bobbin and carriage manufacturer he removed to Chard, prospering to such an extent that a few years later he set up an establishment of his own for the manufacture of lace machinery. Thence onward to his death his prosperity and popularity never waned, and though he has been more than a quarter of a century in his grave there are many in the little Somersetshire town that remember the cheerful and vigorous personality of Stringfellow, the "flying man."

It happened that there was residing at Chard, with his father, a young engineer named William Samuel Henson,* who was deeply interested in the problem of flight. Drawn by mutual engineering interests into friendship with Stringfellow, Henson did not hesitate to confide to him his hopes and aspirations, and it is recorded that during one heroic evening at Stringfellow's house the world-famed aeroplane was planned.

Henson almost immediately afterwards left for London, but correspondence continually passed between the two friends, and Stringfellow, interested more at first in the question of motive power as his undoubted skill in lace-machinery would warrant, began building the first of the series of light steam-engines upon which his reputation principally depends. In 1840 Henson began his experiments with gliding models, tentative constructional devices, and a light steam-engine. The engine seems to have cost him endless trouble in spite of the advice and assistance of Stringfellow, who supplied him with parts for his boiler. At the end of 1841, Stringfellow visited Henson in London and received an order for an engine from his friend, who, in the letter which follows, specified the peculiar cone construction in the boiler, which Stringfellow had probably suggested to him.

7, Ralph Place,
London,
January 10/42.

My dear Sir,

I beg pardon for keeping you so long in suspense, but I unexpectedly went out on Sunday

* Born at Leicester about 1805.

week and I waited to give you some more particulars respecting my little engine. There are two cylinders of 1 inch dia. and 2-inch stroke. At first I cut the steam off at $\frac{1}{4}$ of the stroke, but finding I had plenty of steam, I now cut it off at $\frac{1}{2}$. The boiler consists of two cones, $4\frac{1}{2}$ inches dia. and 7 deep. From the widest part downwards the cylinders are let into the cones in the manner I mentioned to you when you were in town; the cones are like the tin one I showed you at that time, having the upper part large enough to hold one of the cylinders above the water line at wide part. I find your cylinders will hold 3 times the quantity that mine will hold, consequently there should be something more than double the quantity of heating surface, but it will be advisable not to have double the weight of water, a gallon of water weighs about 10 lbs. One quart of water is about the proper quantity for your boiler, it won't last long it's true, but that does not matter. My engine is heavier considerably than it ought to be, in addition to which it holds more water than is necessary. This is against me, but still it is very powerful for its weight, and I have no doubt about making it act. I have not yet got my model sufficiently advanced to have a fly, but I continue as sanguine as ever as to the results. I think you had better make the boiler to consist of several small cones, each holding a very small quantity of water, so as to get about $2\frac{1}{2}$ times the quantity of surface with the same quantity of water—such as 6 or 8 cones of about

3 or 2 inches dia. at the broad part, well studded with copper wire. My engine with water and fuel altogether with the fire-place weighs about 10 lbs., and I am quite sure an engine may be made of double the power with the same weight including everything; and I know also that you can do it and will. I wish much I could have had your engine for my present model, as it would assist so much in making up for those natural defects which all models possess more or less. Wishing you success,

I am, my dear Sir,

Very faithfully yours,

W. S. HENSON.

To John Stringfellow, Esq.

About this time Mr. Colombine, an attorney, and a Mr. Marriott appeared on the scene—Colombine would be necessary for the Company work, settling the patent, etc., while Mr. Marriott knew a Member of Parliament. Besides, they were both extraordinarily excited over the idea which Henson laid before them, and promised to take shares in the Company as soon as it was formed. The patent, No. 9478 of 1842, was taken out in September, an application was made to Parliament for an Act of Incorporation for the Aerial Steam Transit Company, and the M.P., Mr. Roebuck, moved to bring in the Bill on March 24th, 1843. The patent was for "Certain Improvements in Locomotive Apparatus and Machinery for Conveying Letters, Goods, and Passengers from Place to Place through the Air, part of which Improvements are applicable to Locomotive and other

Machinery to be used on Water and on Land," and specified *inter alia* a steam-engine incorporating Stringfellow's suggestions.

Sir George Cayley had shown in 1809 the way to success, and Henson, developing his idea of the resistance offered by the air to surfaces moving through it, evolved the project of a large monoplane singularly like those of the present day, but with flat instead of curved surfaces, a circumstance that robbed him of the success he undoubtedly deserved.

"In order that the description hereafter given may be rendered clear," he wrote in his patent specification (1842, No. 9478), "I will first shortly explain the principle on which the machine is constructed. If any light and flat or nearly flat article be projected or thrown edgewise in a slightly inclined position, the same will rise on the air till the force exerted is expended, when the article so thrown or projected will descend; and it will readily be conceived that, if the article so projected or thrown possessed in itself a continuous power or force equal to that used in throwing or projecting it, the article would continue to ascend so long as the forward part of the surface was upwards in respect to the hinder part, and that such article, when the power was stopped, or when the inclination was reversed, would descend by gravity only if the power was stopped, or by gravity aided by the force of the power contained in the article, if the power be continued, thus imitating the flight of a bird.

"Now, the first part of my invention consists of an apparatus so constructed as to offer a very extended surface or plane of a light yet strong construction,

which will have the same relation to the general machine which the extended wings of a bird have to the body when a bird is skimming in the air; but in place of the movement or power for onward progress being obtained by movement of the extended surface or plane, as is the case with the wings of birds, I apply suitable paddle-wheels or other proper mechanical propellers worked by a steam or other sufficiently light engine, and thus obtain the requisite power for onward movement to the plane or extended surface; and in order to give control as to the upward and downward direction of such a machine I apply a tail to the extended surface which is capable of being inclined or raised, so that when the power is acting to propel the machine, by inclining the tail upwards the resistance offered by the air will cause the machine to rise on the air; and, on the contrary, when the inclination of the tail is reversed, the machine will immediately be propelled downwards, and pass through a plane more or less inclined to the horizon as the inclination of the tail is greater or less; and in order to guide the machine as to the lateral direction which it shall take, I apply a vertical rudder or second tail, and, according as the same is inclined in one direction or the other, so will be the direction of the machine."

The proposed machine itself, as may be seen from the accompanying illustrations (Figs. 1 and 2), was an enormous monoplane, and was to be built of bamboo and hollow wood spars braced with wires. The surface of the planes was to measure 4,500 sq. ft. and the triangular tail 1,500 sq. ft. These dimensions were calculated to sustain $\frac{1}{2}$ lb. to the square foot, in-

cluding the machinery, fuel, and load. A steam-engine of 25-30-h.p. was to drive it, and propulsion was to be effected by two six-bladed propellers with the blades set at an angle of about 45°.

Naturally, the publication of this patent roused public curiosity to a considerable pitch, and the papers of the day produced fanciful pictures of the machine flying over Hyde Park, the Pyramids, the English Channel and the Thames at London Bridge, and published

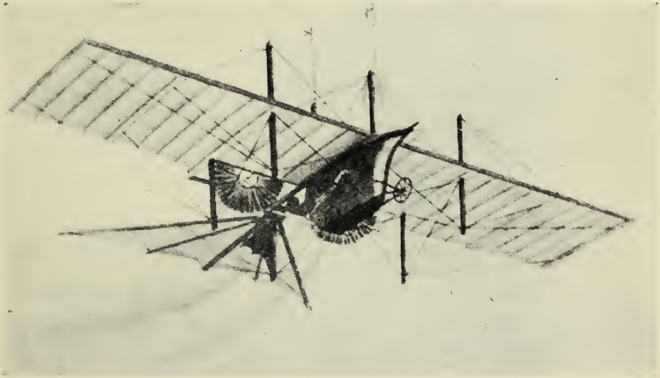


Fig. 1

articles in which scientists either totally condemned or fervently endorsed the new wonder.

Henson, Stringfellow, Colombine, and Marriott took shares in the Company, and Colombine drew up the following prospectus appealing for funds :—

PROPOSAL

For subscriptions of sums of £100, in furtherance of an Extraordinary Invention not at present safe to be developed by securing

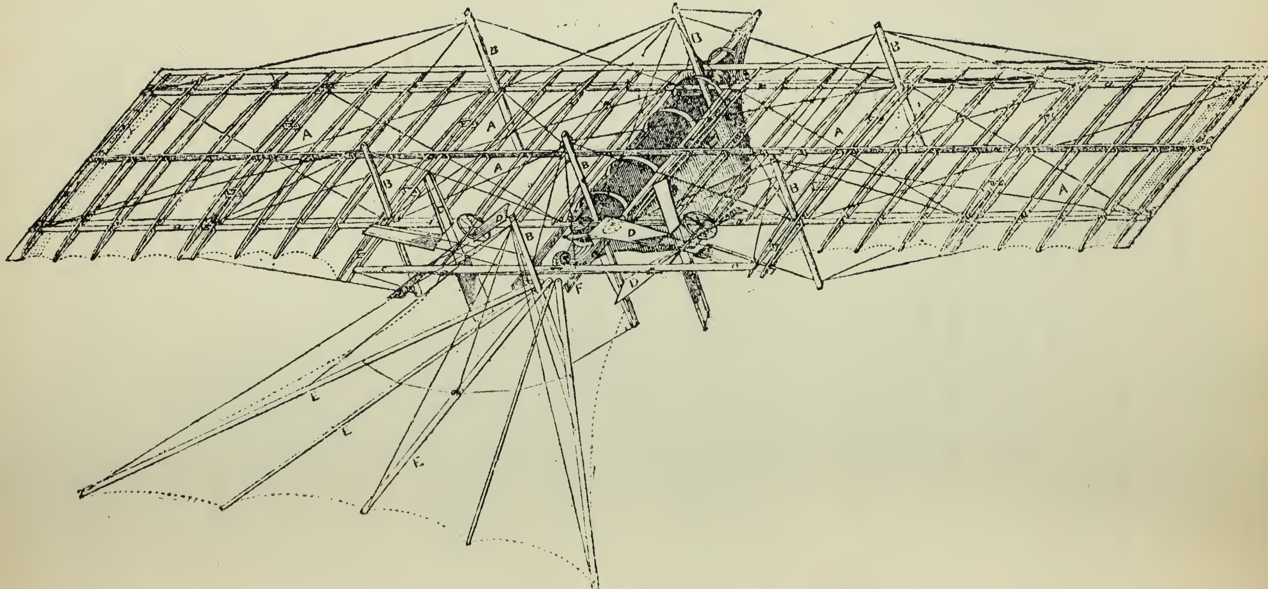


Fig. 2

the necessary Patents, for which three times the sum advanced, namely, £300, is conditionally guaranteed for each subscription on February 1, 1844, in case of the anticipations being realised, with the option of the subscribers being shareholders for the large amount, if so desired, but not otherwise.

An Invention has recently been discovered, which if ultimately successful will be without parallel even in the age which introduced to the world the wonderful effects of gas and of steam.

The discovery is of that peculiar nature, so simple in principle yet so perfect in all the ingredients required for complete and permanent success, that to promulgate it at present would wholly defeat its development by the immense competition which would ensue, and the views of the Originator be entirely frustrated.

This work, the result of years of labor and study, presents a wonderful instance of the adaptation of laws long since proved to the scientific world combined with established principles so judiciously and carefully arranged, as to produce a discovery perfect in all its parts and alike in harmony with the laws of Nature and of science.

The Invention has been subjected to several tests and examinations and the results are most satisfactory, so much so that nothing but the completion of the undertaking is required to determine its practical operation, which being once established its utility is undoubted, as it would be a necessary possession of every empire, and it were hardly too much to say of every individual of competent means in the civilised world.

Its qualities and capabilities are so vast that it were impossible and, even if possible, unsafe to develop them further, but some idea may be formed from the fact that as a preliminary measure patents in Great Britain, Ireland, Scotland, the Colonies, France, Belgium, and the United States, and every other country where protection to the first discoveries of an Invention is granted, will of necessity be immediately obtained and by the time these are perfected, which it is estimated will be in the month of February, the invention will be fit for Public Trial, but until the Patents are sealed any further disclosure would be most dangerous to the principle on which it is based.

Under these circumstances, it is proposed to raise an immediate sum of £2,000 in furtherance of the Projector's views, and as some protection to the parties who may embark in the

matter, that this is not a visionary plan for objects imperfectly considered, Mr. Colombine, to whom the secret has been confided, has allowed his name to be used on the occasion and who will if referred to corroborate this statement, and convince any inquirer of the reasonable prospects of large pecuniary results following the development of the Invention.

It is therefore intended to raise the sum of £2,000 in 20 sums of £100 each (of which any Subscriber may take one or more not exceeding five in number to be held by any individual) the amount of which is to be paid into the hands of Mr. Colombine as General Manager of the concern to be by him appropriated in procuring the several Patents and providing the expenses incidental to the works in progress. For each of which sums of £100 it is intended and agreed that 12 months after the 1st February next, the several parties subscribing shall receive as an equivalent for the risk to be run the sum of £300* for each of the sums of £100 now subscribed provided when the time arrives the Patents shall be found to answer the purposes intended.

As full and complete success is alone looked to, no moderate or imperfect benefit is to be anticipated, but the work, if it once passes the necessary ordeal, to which inventions of every kind must be first subject, will then be regarded by everyone as the most astonishing discovery of modern times; no half success can follow, and therefore the full nature of the risk is immediately ascertained.

The intention is to work and prove the Patent by collective instead of individual aid as less hazardous at first and more advantageous in the result for the Inventor, as well as others, by having the interest of several engaged in aiding one common object—the development of a Great Plan. The failure is not feared, yet as perfect success might, by possibility, not ensue, it is necessary to provide for that result, and the parties concerned make it a condition that no return of the subscribed money shall be required, if the Patents shall by any unforeseen circumstances not be capable of being worked at all; against which, the first application of the money subscribed, that of securing the Patents, affords a reasonable security, as no one without solid grounds would think of such an expenditure.

It is perfectly needless to state that no risk or responsibility of any kind can arise beyond the payment of the sum to be subscribed under any circumstances whatever.

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* This sum was afterwards altered to £500, though, needless to add, it was never paid.

As soon as the Patents shall be perfected and proved it is contemplated, so far as may be found practicable, to further the great object in view a Company shall be formed but respecting which it is unnecessary to state further details, than that a preference will be given to all those persons who now subscribe, and to whom shares shall be appropriated accordingly the larger amount (being three times the sum to be paid by each person) contemplated to be returned as soon as the success of the Invention shall have been established, at their option, or the money paid, whereby the Subscriber will have the means of either withdrawing with a large pecuniary benefit, or by continuing his interest in the concern, lay the foundation for participating in the immense benefit which must follow the success of the plan.

It is not pretended to conceal that the project is a speculation—all parties believe that perfect success, and thence incalculable advantages of every kind, will follow to every individual joining in this great undertaking; but the Gentlemen engaged in it wish that no concealment of the consequences, perfect success, or possible failure, should in the slightest degree be inferred. They believe this will prove the germ of a mighty work, and in that belief call for the operation of others with no visionary object, but a legitimate one before them, to attain that point where perfect success will be secured from their combined exertions.

All applications to be made to D. E. Colombine, Esquire, 8, Carlton Chambers, Regent Street.

The public do not, however, seem to have got beyond verbal and pictorial speculation in the venture, and Mr. Roebuck declared that he had risked quite enough in bringing in the Bill. Colombine agitated, squibbed, and advertised; Henson conducted some experiments with models in the Adelaide Gallery, and, finding himself cramped for room, removed to a tent on the Hippodrome racecourse, Bayswater, "2 miles from the end of Oxford Street," for a fortnight; but all to no purpose.

Meanwhile, Stringfellow, who had been promised the construction of the machine as soon as funds were forthcoming, grew impatient, and in November, 1843, wrote urgently to Henson suggesting that they should

construct a large model out of their private resources and trust to a happy issue for repayment. To this Henson replied as follows :—

7, Ralph Place,
Trinity Square, Borough,
London,
November 18/43.

My dear Sir,

I received your letter this morning and, as there is no post out of London to-morrow, I just drop you a line to say that I think you are quite right in your views. I knew how you would feel in the matter, and I said distinctly that whoever I might get to carry out the matter would expect to have the control of it during progress and very liberal treatment also, and that, in fact, neither of them (Colombine or Marriott) would know anything about it until it was done; if it succeeded they would have to fulfil the contract, if not, they would hear no more about it. I shall leave a note at Colombine's to-day to ask him for a rough copy or sketch of the terms for you, so that I think you will hear from me again on Tuesday or Wednesday. I quite agree with you about the Lawyer's. Don't you think the buying the patent—I mean Colombine and Marriott shares—would be a good move? I am quite sure that by good management the money could be got out of it again, even with only partial success. I shall have a try to get it into other hands yet, as I

don't think it would prejudice an arrangement with you. Hoping you are better,

I am, my dear Sir,

Very faithfully yours,

W. S. HENSON.

P.S.—Remember me kindly to Mrs. Stringfellow and family.

Colombine and Marriott were accordingly bought out. With the agreement* in his pocket Henson travelled down to Chard that Christmas, and for the next few years no more was heard of the giant aeroplane.

The two inventors, however, were hard at work. "They commenced the construction of a small model operated by a spring, and laid down the larger model 20 ft. from tip to tip of planes, 3½ ft. wide, giving 70 ft. of sustaining surface, about 10 more in the tail. The making of this model required great consideration; various supports for the wings were

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* Memorandum of an agreement entered into by Mr. John Stringfellow, of Chard, in the County of Somerset, of one part, and Mr. Wm. Saml. Henson, of No. 7, Ralph Place, near Trinity Square, of the Borough of Southwark, of the other part.

Whereas it is intended to construct a model of an Aerial Machine to be employed in such a manner as the parties above named shall consider best and most profitable.

1st. It is agreed, if considered necessary, to take out patents for the same jointly, but be it understood that this agreement does not extend to England except for such parts as are improvements upon patent already taken out in England.

2nd. That all moneys advanced to be considered as lent and to be deducted from the profits that may arise hereafter.

3rd. That all profits after deducting expenses be equally divided.

tried, so as to combine lightness with firmness, strength, and rigidity.

"The planes were staid from three sets of fish-shaped masts, and rigged square and firm by flat steel rigging. The engine and boiler were put in the car to drive two screw propellers, right and left handed, 3 ft. in diameter, with four blades each, occupying three-quarters of the area of the circumference, set at an angle of 60 degrees. A considerable time was spent in perfecting the motive power. Compressed air was tried and abandoned. Tappets, cams, and eccentrics were all tried, to work the slide valve, to obtain the best results. The piston rod of engine passed through both ends of the cylinder, and with long connecting rods worked direct on the crank of the propellers. From memorandum of experiments still preserved the following is a copy of one:—June, 27th, 1845, water 50 ozs., spirit 10 ozs., lamp lit 8.45, gauge moves 8.46, engine started 8.48 (100 lb. pressure), engine stopped 8.57, worked 9 minutes, 2,288 revolutions, average 254 per minute. No priming,

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4th. That it is the intention of this agreement that the parties above named shall be on perfect equality as regards carrying out and working the same.

5th. That it is intended at a future time, if considered necessary and desirable, to enter into an agreement more definite and explicit, according as circumstances may arise to require it.

6th. That the parties hereby pledge themselves in honour to each other to do all that lies in their power towards carrying out the objects of this agreement.

7th. That nothing herein mentioned shall be construed into a partnership beyond carrying out jointly the objects of this agreement.

(Signed) W. S. HENSON.
(Signed) J. STRINGFELLOW.

December 29th, 1843.

40 ozs. water consumed, propulsion (thrust of propellers), 5 lbs. 4½ ozs. at commencement, steady, 4 lbs. ½ oz., 57 revolutions to 1 oz. water, steam cut off one-third from beginning.

"The diameter of cylinder of engine was one-and-a-half inch, length of stroke three inches.

"In the meantime an engine was also made for the smaller model, and a wing action tried, but with poor results. The time was mostly devoted to the larger model, and in 1847 a tent was erected on Bala Down, about two miles from Chard, and the model taken up one night by the workmen. The experiments were not so favourable as was expected. The machine could not support itself for any distance, but, when launched off, gradually descended. Although the power and surface should have been ample, indeed, according to latest calculations, the thrust should have carried more than three times the weight, for there was a thrust of five pounds from the propellers, and a surface of over 70 square feet to sustain under 30 lbs., but necessary speed was lacking."*

Stringfellow himself wrote of this splendid failure :—"There stood our aerial protégée in all her purity—too delicate, too fragile, too beautiful for this rough world; at least, those were my ideas at the time, but little did I think how soon it was to be realised. I soon found,

* "A few Remarks on what has been done with screw-propelled Aero-plane Machines from 1809 to 1892," by F. J. Stringfellow, Crewkerne, Somerset (Chard: Young & Son, N.D. pp. 14. Photographs). In this rare little pamphlet Mr. Stringfellow gives some account of his father's and his own experiments, from which much of the information included in this memoir is taken. Mr. F. J. Stringfellow died on August 25, 1905.

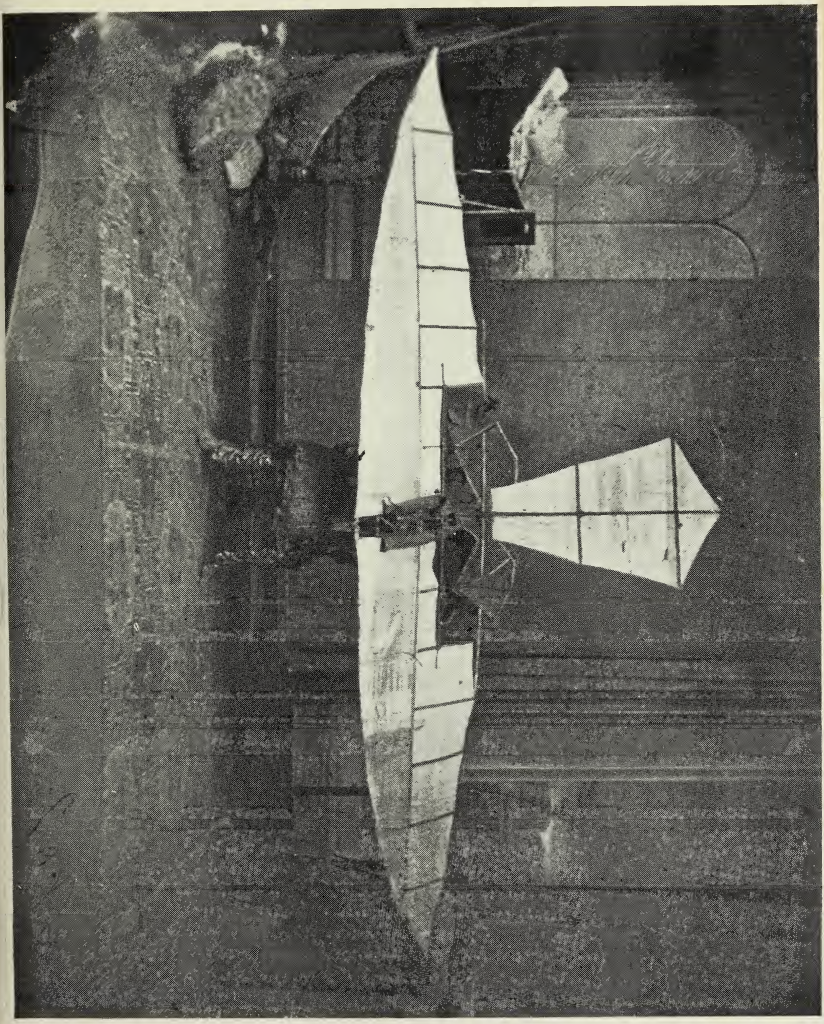
before I had time to introduce the spark, a drooping in the wings, a flagging in all the parts. In less than ten minutes the machine was saturated with wet from a deposit of dew, so that anything like a trial was impossible by night. I did not consider we could get the silk tight and rigid enough. Indeed, the framework altogether was too weak. The steam-engine was the best part. Our want of success was not for want of power or sustaining surface, but for want of proper adaptation of the means to the end of the various parts."

For seven weeks successive experiments took place on the Downs, but the trials by running the machine down wide rails showed faulty construction and its lightness made it unmanageable in the slightest wind.

Discouraged and impoverished, Henson refused to go any further in the work. His London landlady's daughter, Miss Jones, threw the casting vote for matrimony against mechanics, and in 1849 he left with his wife for America, disappearing in the wilds of Texas from the ken of aeronautical science.

If Stringfellow was dismayed by the turn of events, he was not discouraged. Henson had gone, but he had learnt all that Henson knew, and was the richer for several years of practical experience. Accordingly, in 1846, he set to work on the small model upon which for all time his fame will rest as being the first engine-driven aeroplane to fly. This historic machine* was 10 ft. in span and 2 ft. across in the widest part of the wings; length of tail 3 ft. 6 ins., span of tail in widest

* See Fig. 3.



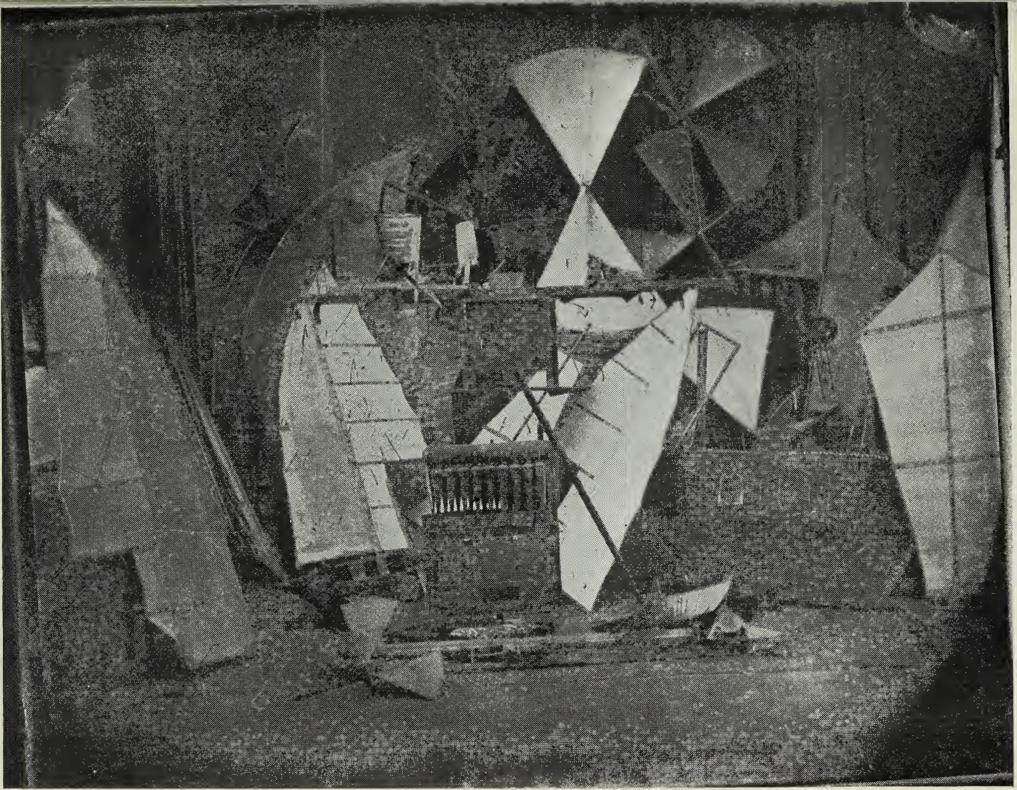


Fig. 5.—Relics of Stringfellow's Experiments
(A steam-engine is in the centre)

part 22 ins.; the total sustaining area was about 14 sq. ft. The two propellers—a right and a left screw—had four blades set at an angle of 60 degrees, occupying three-quarters of the area of the circumference, and were 16 ins. in diameter.

The cylinder of the engine was of $\frac{3}{4}$ in. diameter with a 2-in. stroke and a bevel gear to the crank shaft gave three revolutions of the propellers to one stroke of the engine. The weight of the entire model and engine was eight pounds—with water and fuel half-a-pound more. That his model actually flew was due in large measure to the wing form : slightly curved with a rigid front edge and a flexible trailing edge—a form of construction advocated by Da Vinci and Borelli, and re-discovered repeatedly by investigators for several hundred years, but until this moment never carried out. Stringfellow probably got the idea of the curve from Sir George Cayley, though certainly some credit should rest with Thomas Walker,* who advocated the flexible rear-edge in 1810, and with Dr. Thomas Young, who in 1800 proved that certain curved surfaces advanced into an impinging air-current.

The fullest account of the flight is given by his son, F. J. Stringfellow,† and is here quoted :—"My father had constructed another small model which was finished early in 1848, and having the loan of a long room in a disused lace factory, early in June the small model was moved there for experiments. The room was about 22 yards long and from 10 to 12 ft. high. . . . . . The inclined wire for starting the machine occupied less than

* *Vide* "Aeronautical Classics," No. 3.

† *Vide* "Screw-Propelled Aero-plane Machines."

half the length of the room and left space at the end for the machine to clear the floor. In the first experiment the tail was set at too high an angle, and the machine rose too rapidly on leaving the wire. After going a few yards it slid back as if coming down an inclined plane at such an angle that the point of the tail struck the ground and was broken. The tail was repaired and set at a smaller angle. The steam was again got up, and the machine started down the wire, and, upon reaching the point of self-detachment, it gradually rose until it reached the farther end of the room, striking a hole in the canvas placed to stop it. In experiments the machine flew well, when rising as much as one in seven. The late J. Riste, Esq., lace manufacturer, Northcote Spicer, Esq., J. Toms, Esq., and others witnessed experiments. Mr. Marriatt, late of the San Francisco 'News Letter,' brought down from London Mr. Ellis, the then lessee of Cremorne Gardens, Mr. Partridge, and Lieutenant Gale, the aeronaut, to witness experiments. Mr. Ellis offered to construct a covered way at Cremorne for experiments. Mr. Stringfellow repaired to Cremorne, but not much better accommodations than he had at home were provided, owing to unfulfilled engagement as to room. Mr. Stringfellow was preparing for departure when a party of gentlemen unconnected with the Gardens begged to see an experiment, and finding them able to appreciate his endeavours, he got up steam and started the model down the wire. When it arrived at the spot where it should leave the wire it appeared to meet with some obstruction, and threatened to come to the ground, but it soon recovered itself and darted off in as fair a

flight as it was possible to make to a distance of about 40 yards, where it was stopped by the canvas.

"Having now demonstrated the practicability of making a steam-engine fly, and finding nothing but a pecuniary loss and little honour, this experimenter rested for a long time, satisfied with what he had effected. The subject, however, had to him special charms, and he still contemplated the renewal of his experiments."

The launching apparatus, which was used in these and other experiments, while simple, is of sufficient in-

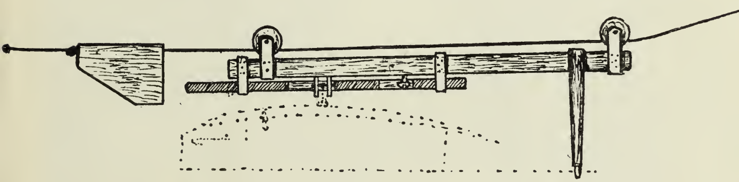


Fig. 4.—Stringfellow's Launching Apparatus

terest to warrant a description. It consisted essentially of three pieces of wood, two horizontal and one vertical (see Fig. 4). The larger horizontal member was slung from a stout wire by two grooved wheels; the small member—shown in section—was attached beneath it in such a way as to be free to slide an inch or two, the total movement of which was adjusted by means of a small screw fixed into the top member and passing

through the lower by means of a slot. In another similar slot two eye-bolts projected through which passed a steel pin attached to the lower member.

The model was suspended at its front end by a wire or string loop slipped over the steel pin in the position shown in the sketch. The tail or the rear projection of the hull or body was supported by the vertical member by means of two wire eye-bolts at its lower extremity. The model and apparatus ran down the slanting wire until a wooden block fixed on the wire was encountered. By the impact the projecting lower member was pushed back, and, simultaneously, the pin sliding back, released the loop. The inertia of the model drew it out of the rear support, and it was thus launched in free flight.

The following year Stringfellow travelled in America with his son, and on their return many years passed before the aerial problem was again attacked. The engine of the 1848 model was given to Messrs. Heathcote, of Tiverton, to drive a small lace-machine, and the relics of his experiments lay in idleness and neglect.

But his energies, dormant for more than 15 years, were destined to be aroused, for in 1866 the Aëronautical Society of Great Britain was founded under the presidency of the Duke of Argyll, and the following year he received a visit from Mr. F. W. Brearey, the Hon. Secretary. Stringfellow's old enthusiasm had been re-awakened by Wenham's now classic paper on "Aerial Locomotion,"* and, hearing that the Aëro-

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* *Vide* "Aeronautical Classics," No. 2.

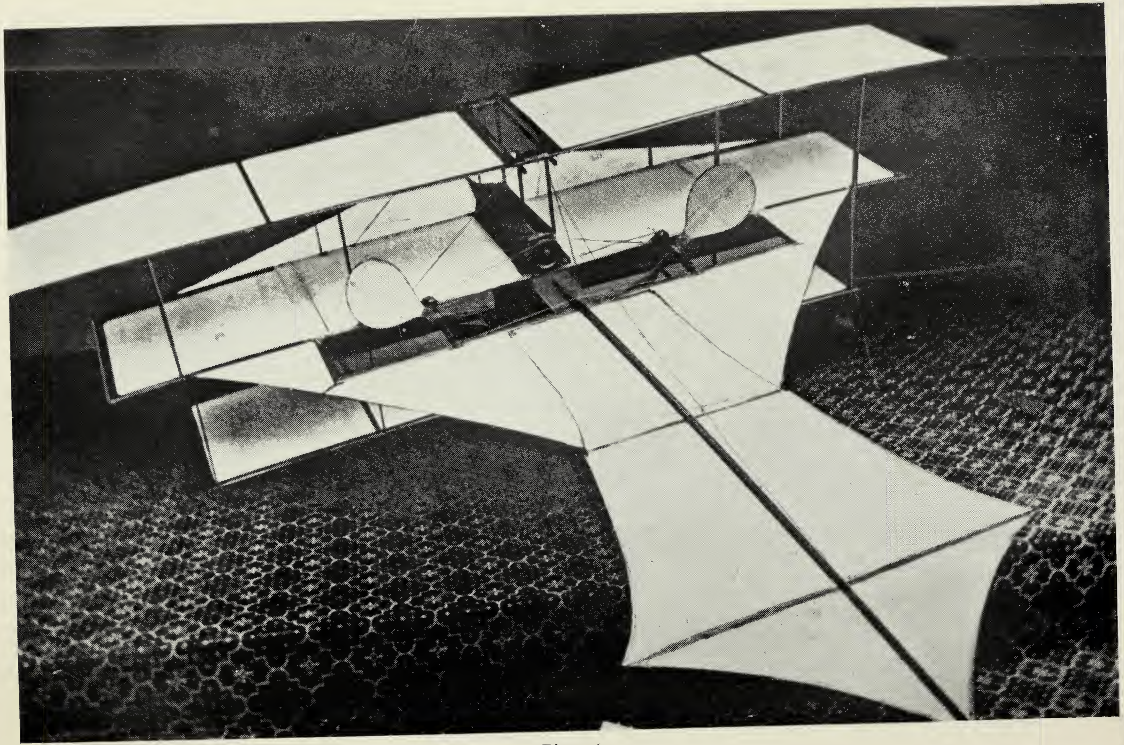


Fig. 6

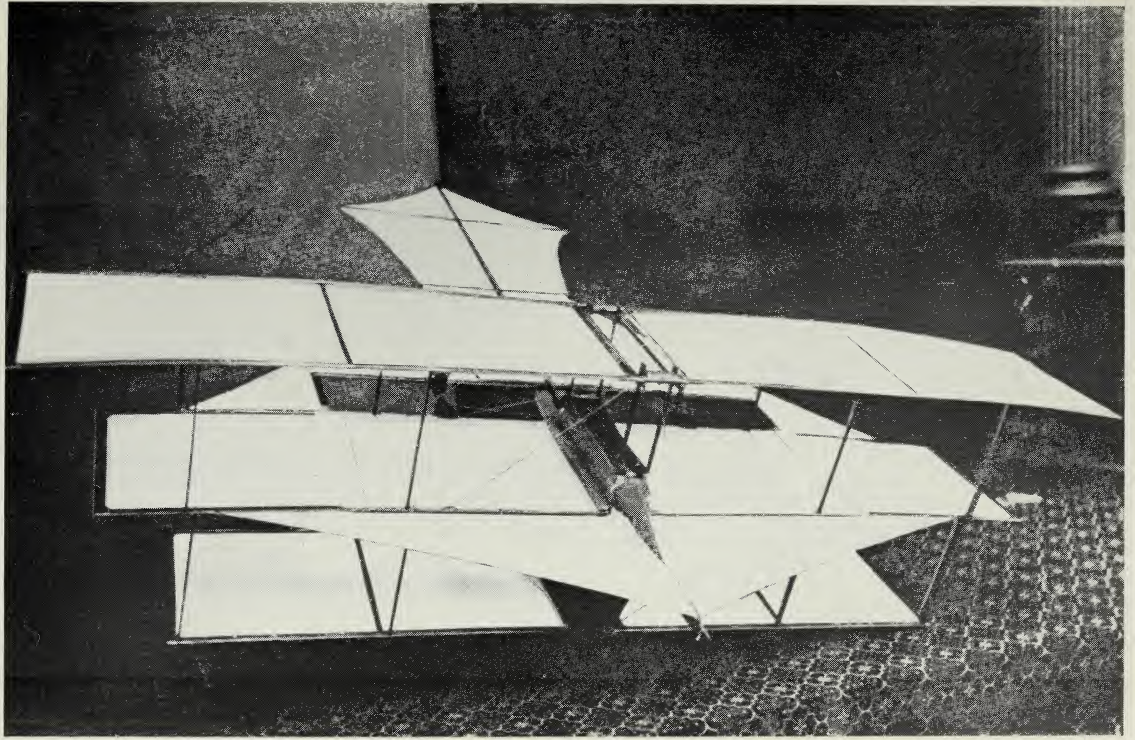


Fig. 7

Fig. 8

The First Exhibition of the Aëronautical Society at the Crystal Palace, July, 1868.

The energetic figure on the left (marked with a cross) is John Stringfellow, and above him hangs his model triplane.

Fig. 8

The First Exhibition of the Aëronautical Society at the Crystal Palace, July, 1868.

The energetic figure on the left (marked with a cross) is John Stringfellow, and above him hangs his model triplane.

nautical Society proposed to hold an Aeronautical Exhibition in 1868 at the Crystal Palace, he resumed his long-interrupted work. Acting upon Wenham's suggestions for a machine with superposed planes he constructed a triplane model (see Figs. 6 and 7), and also a light aerial engine of rather more than one horse-power, and a one horse-power copper boiler and fire-place weighing about 40 lbs. and capable of sustaining a pressure of 500 lbs. to the square inch.

The triplane, which ran suspended from a wire in the nave of the Crystal Palace, contained, excluding the tail, a surface of 28 sq. ft., and weighed, including engine, boiler, fuel, and water, under 12 lbs. The engine, with a 1 3-16-in. cylinder and a 2-in. stroke, worked two propellers, 21 inches in diameter, at about 600 revolutions per minute and got up steam to 100 lbs. pressure in five minutes. It developed $\frac{1}{3}$ h.p. On account of danger from fire no free flight was allowed in the building, but the Aëronautical Society's Jurors' Committee and the reporters* observed that it lifted considerably when running along the wire. "It was a grand day for Uncle," wrote his niece, Rosa, to Mrs. Stringfellow, who, unfortunately, was prevented from coming to London to share her husband's triumph. "The Prince and Princess of Wales [afterwards King Edward VII. and Queen Alexandra], and Prince Alfred, and several of the Princesses with their train were there. The Prince was so charmed with the model that he sent the Duke of Sutherland for Uncle to go to the Royal Box."

* "Morning Star," July 6th, 1868, and "Standard," July 6th, 1868.

The steam-engine was awarded the prize of £100 for "the lightest steam-engine in proportion to its power" and was very fully described in the Society's Report on the Exhibition as follows:—"The cylinder is 2 ins. in diameter, stroke 3 ins., and works with a boiler pressure of 100 lbs. per square inch; the engine making 300 revolutions per minute. The time of getting up steam was noted; in three minutes after lighting the fire the pressure was 30 lbs., in five minutes 50 lbs., and in seven minutes there was the full working pressure of 100 lbs. When started the engine had a fair amount of duty to perform in driving two four-bladed screw propellers 3 ft. in diameter at 300 revolutions per minute.

"The data for estimating the power are taken as follows:—Area of piston 3 ins., pressure in cylinder 80 lbs. per square inch, length of stroke 3 ins., velocity of piston 150 ft. per minute, $3 \times 80 \times 150 = 36{,}000$ foot-pounds; this makes rather more than one horse-power (which is reckoned as 33,000 foot-pounds). The weight of the engine and boiler was only 13 lbs., and is probably the lightest steam-engine that has ever been constructed. The engine, boiler, car, and propellers together were afterwards weighed, but without water and fuel, and were found to be 16 lbs.

"The two-inch cylinder is of very thin brass tube; the covers, flanges, and glands are also as light as they can be made consistently with strength; the ports and passages are in one separate piece, screwed on; the piston-rod passes through each end of the cylinder, and, by means of long connecting-rods, works in opposite

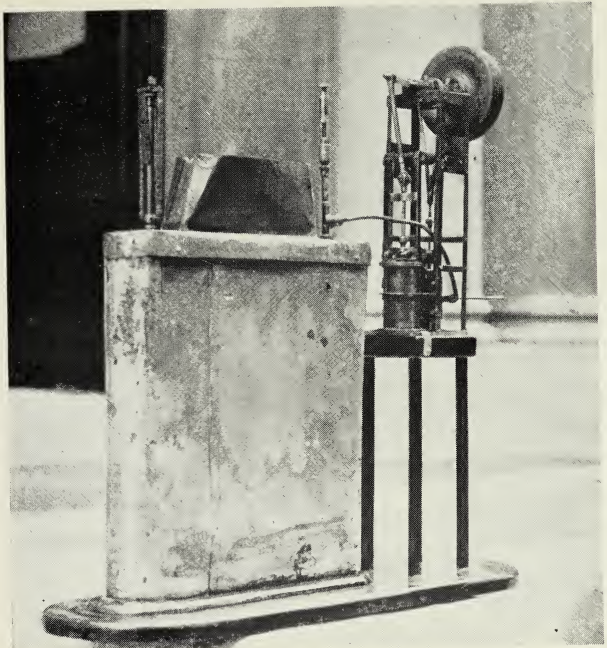
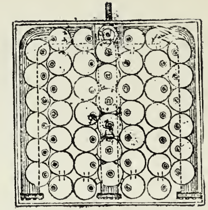
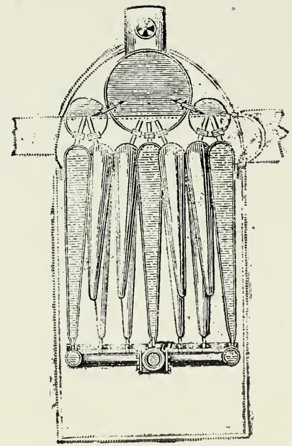


Fig. 9
One of Stringfellow's light Steam Engines for model Aeroplanes
(Now in the possession of the Aeronautical Society)



Horizontal Section of Boiler



Upright Section of tho Boiler

directions two cranks fitted to the axes of two four-bladed screws three feet in diameter; two light bars extend from the crank shaft down each side of the cylinder; these sustain the thrust of the piston, and a framing is thus almost dispensed with. The boiler consists of a number of inverted cones made of very thin sheet copper, with the joints soldered with silver solder; each cone is closed with a hemispherical cap. The cones are placed in parallel rows, the bottom ends or apexes of the series are all connected together by water tubes, and from the hemispherical tops a small steam-pipe conveys the steam away to a cylindrical chamber above the system; this is set in the smoke-box, and serves as a super-heater, and the steam is quite dried therein. The cones are not liable to prime, as the water surface for the escape of the steam is extensive, and the steam rises clear from the generating surfaces. The fire space betwen the bases being large and free, this form of boiler is particularly well adapted for burning liquid fuels. The question may be asked, is there not some hazard in employing metal almost as thin as paper for sustaining pressures exceeding 100 lbs. per square inch? But it is well known that in the so-termed 'tubulous' boilers, to which class this one belongs, if a rupture takes place in one of the elements a gradual and harmless escape of water and steam is the only consequence; this empties the boiler by degrees, and at the same time ends the danger by extinguishing the fire, thus differing in character to the explosion of a boiler, whose strength depends upon the external shell, the fracture of which causes instant destruction, both to itself and all within its vicinity."

For some time after this crowning effort Stringfellow pursued his work. He became a Member of the Aëronautical Society in 1868 and erected a building over 70 feet long for experimental purposes with the £100 awarded to him. But his eyesight began to fail; he was over seventy and he felt that his work was done. He lingered on, however, until 1883, when on December 13th he quietly passed away.

John Stringfellow possessed ideal qualities for his work. A clever mechanic with some private resources, energetic, level-headed and enthusiastic, he was able to use his knowledge to the fullest advantage. Moreover, in the words of Mr. Brearey, "his aspirations were fixed more upon the attainment of success in a special mechanical problem than upon the acquisition of wealth." Posterity has set the seal of success upon his labours by enrolling him among the immortals.

* * * * *

The editors desire to express their great indebtedness to Mr. V. B. T. Stringfellow (grandson), of Yeovil and to Mr. C. H. Alderson, of Farnborough, Kent, who have kindly placed photographs and much valuable material at their disposal for the compilation of this memoir. It was through the energy, researches, and personal labour of Mr. Alderson that the Henson-Stringfellow model and the Stringfellow model of 1848 were discovered and preserved for the nation. The generosity of Mr. P. Y. Alexander enabled him to restore these models, which were subsequently presented by these two gentlemen to the Victoria and Albert Museum.

The triplane and the light engine exhibited at the Crystal Palace in 1868 were bought in 1889 by Professor S. P. Langley, and are now in the Museum at Washington, D.C.

F. J. STRINGFELLOW

(*Vide* footnote page 29)

THE FLIGHT OF BIRDS

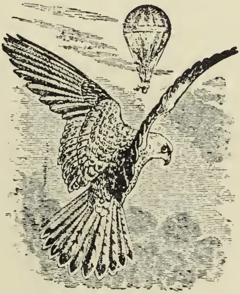
TITLE PAGE TO 2nd EDITION

Aeronautical Classics — **No. 6**

THE FLIGHT OF BIRDS

BY

GIOVANNI A. BORELLI



PRINTED AND PUBLISHED FOR

THE AËRONAUTICAL SOCIETY OF GREAT BRITAIN

By KING, SELL & OLDING, LTD., 27, Chancery Lane, W.C.

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1911

BIOGRAPHICAL NOTICE

The history of the 17th century is particularly remarkable for the rise of scientific learning which was the natural corollary to the revival of letters in the preceding hundred years. This period, in fact, bristles with erudite men, who with immense industry gathered up all the scientific lore of the ancient world, re-wrote it with voluminous commentaries and dissertations, and then boldly set out on the wide basis their labours had founded to build up all the branches of human science. Not the least among these was Giovanni Alphonso Borelli, son of Michael Alonzo and Laura, who was born at Naples on January 28, 1608. Of his early life very little is known, but at the age of forty he had already an established reputation in mathematics, anatomy, astronomy, and philosophy, and corresponded with many prominent members of the Royal Society of Great Britain; among others with Boyle, John Collins, Dr. Wallis, and the Secretary, Henry Oldenburgh. He held professorships at the Universities of Florence and of Pisa, and was in high favour with the princes of the house of Medici. About 1670 he lived for a short time at Messina, where he wrote a curious treatise—published in 1676—on the cause of the eruption of Mount Etna in 1669. During

the revolt of Messina against the Spaniards in 1672 he was proclaimed a political suspect; therefore, returning to Italy, he settled near Rome, under the protection of Christine, the eccentric ex-Queen of Sweden, whose liberality considerably lightened the troubles of his later years. Shortly before he died he acted for two years as mathematical instructor in the convent of the regular clergy of St. Pantaleon, called the Pious Schools, where, it is related, he caused some flutter among the brethren which only his infirm age and reputation prevented from development into outcry, by attaching more importance to the pursuit of scientific knowledge than to the coming of the heavenly kingdom. His death occurred of pleurisy on December 31, 1679.

Of the long list of works that issued from his pen two only have carried his fame through the following centuries to modern times: "Theorice Medicæarum Planetarum," published at Florence, and the better-known posthumous "De Motu Animalium." The former deals with the movement of Jupiter's satellites, and exhibits an instinctive knowledge of gravitation without actually expressing it—a common characteristic of scientists of that day who "were wiser than they knew." The publication of "De Motu Animalium," the year after his death, put Borelli at once at the head of the Iatromathematical School, who sought to apply mathematics to the mechanics of living bodies. It raised a vast storm of discussion among the learned throughout Europe, a ferment that clarified into admiration.

The first part of this work deals with the mechanical action of the limbs of birds and animals, while his

second considers a mechanical theory of the action of internal organs. The section called "De Volatu" in the first volume—which is translated in the following pages for the first time into English—is the only one that here concerns us. Da Vinci's earlier work on the subject of bird flight was then unknown—in fact, it lay undiscovered until the end of the 19th century—and "De Volatu" stands as an original study.

Substantially it is remarkably sound, and knowledge of it is an essential preliminary to any examination of the flight of birds. The Duke of Argyll* refers to the "admirable account" Borelli gives of the means by which birds are able to turn in the air and devotes a couple of pages to refuting his arguments on steerage in flight; Marey† writes "in the works of Borelli we find the first correct idea of the mechanism of flight. The wing, says this writer, acts on the air like a wedge. Developing still further the thought of the learned Neapolitan physiologist, we should now say that the wing of the bird acts on the air after the manner of the inclined plane. . . . therefore we must be allowed to render to the genius of Borelli the justice which is due to him, and only claim for ourselves the merit of having furnished the experimental demonstration of a truth already suspected." Pettigrew‡ explains Borelli's position at great length chiefly because "his doctrines have remained unquestioned for nearly two centuries and have been adopted by all the

* "The Reign of Law," by the Duke of Argyll; London, 1866.

† "Animal Mechanism," ("La Machine animale," 1873), by J. Marey; London, 1874.

‡ "Aerial Locomotion," by J. B. Pettigrew; London, 1874.

writers since his time, without, I regret to say, in the majority of cases, any acknowledgment whatever" and because "in commenting upon and differing from Borelli I will necessarily comment upon and differ from all his successors"; but he, too, gives him tribute when he states "it will not be too much to affirm that to this distinguished physiologist and mathematician belongs almost all the knowledge we possess of artificial wings up to 1865. He was well acquainted with the properties of the wedge, as applied to flight, and he was likewise cognisant of the flexible and elastic properties of the wing. To him is to be traced the purely mechanical theory of the wing's action."

To the verdict of these authorities there is nothing to add, save to draw attention to Borelli's over-estimate of the power exerted by birds to maintain flight in his attempt to deduce it from the ratio between the weight of their muscles and their total weight. Borelli was human, and he made errors; but in the triumphant history of man's progress up to flight he has justly earned his place beside Leonardo da Vinci.

Note.—*The Editors, in preparing this volume, have endeavoured to make their translation as literal as possible; the chapters are given almost word for word, and there is no attempt at paraphrase to conform with modern expression. Their purpose has been to preserve, as far as possible, the flavour of the original.*

The section "De Volatu" is given in its entirety, save for Propositions CLXXXIV., CLXXXVI., CLXXXVII., *which have been omitted as they are of no general interest in the argument.*

THE FLIGHT OF BIRDS

As the beasts of the earth move on the land, so do the Birds wing their flight through the air. This motion of fli ht is accomplished with marvellous skill and by means of organic mechanism in such fashion as we shall here endeavour to set out.

¶ *The wing-structure and its component parts*

All biped and quadruped animals possess, in addition to their hind-legs, two arms, attached to the shoulder-blades, which are used by the quadruped for walking, by man for grasping, and by the Bird for flying. In all these various animals the arms are composed of the same number of joints, and the principal bones are similarly arranged: The shoulder-blade (*scapula*), the arm (*humerus*), the fore-arm (*cubitus* and *radius*), and the hand (*carpus*).

The shoulder-blades are rigidly joined to the extreme ends of the collar-bone (*clavicula*); which springs from the centre of the upper part of the breast-bone (*sternum*). But in Birds the shoulder-blade is of a different struc-

ture, most cunningly devised; it consists, namely, of the two long bones D L and D M, forming the acute angle L D M, of which the upper one L D adheres to the dorsal ribs, and is attached by several muscles to the spine.

The flat round extremity M of the lower scapular

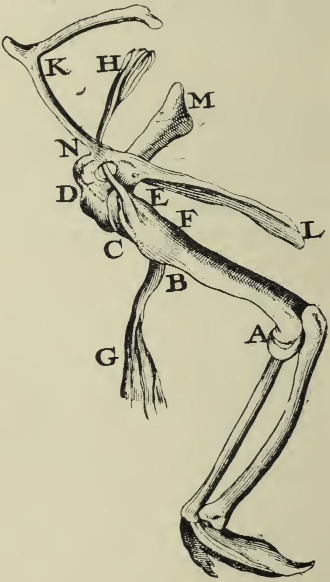


Fig. 1

bone (*coracoid*) is most strongly attached by a tendon to the side of the breast-bone. In the angle N of the shoulder-blade adheres one end of the collar-bone K N, and in the angle D of the shoulder-blade there is a

round socket in which rotates the upper end of the arm-bone, attached there by a mighty tendon.

Furthermore in the hollow of the shoulder-blade there is a hole I*, through which runs, like a pulley, the tendon C I H of the muscle that raises the wing. Once more we may observe with admiration the value of Nature's foresight since the centre about which the wing rotates is most firmly placed on the twin fulcra of the bone D M, which forms the lower scapular bone, and of the collar-bone K N, these fulcra being supported by the crest of the breast-bone; and in this manner they are able to withstand the strongest movements of the pectoral muscle B G which depresses the wing. Two bones, forming the fore-arm (*cubitus* and *radius*), which are longer than the arm (*humerus*), are joined on to its extremity. To these again are attached the carpal bones, which in man are the hand, and in a Bird form the extreme portion of the wing. In length the carpus is slightly less than the arm.

The length of the wing-bones and of the feathers is not uniform in all Birds; that is to say, they have not the same proportion to the length of the Bird's body. For Ostriches have wings very short and slender in comparison to their huge bodies; Fowls and like Birds, which seldom, and then but for a short space, rise and fly, have somewhat larger wings; Pigeons larger still; but the greatest spread of wing is possessed by Eagles, Swans, Swallows, and those other Birds that are nearly always on the wing. In all these the wing-bones in length are equal to or greater than the length

* Shown, but not marked, in Fig. 1.—Eds.

of the body of the Bird, measured from the end of the neck to the coccyx, and with their feathers added they are nearly thrice as long.

The structure of the bones of a Bird also is admirable: for these consist of thin tubes of exceeding hardness, the walls whereof are much thinner than in the bones of men or quadrupeds. The reason for this is, as Galileo showed in masterly fashion in his new science of mechanics, that the weight of the bones is diminished but their strength and resistance increased by this tubular form, so that Birds might be adapted to fly well with light but strong wings.

With marvellous shrewdness, too, has Nature fashioned the feathers of the wings, so that they might strike the air with a strong beat, lightly, powerfully, and with the elasticity of a bow. Their substance is cartilaginous, yet hard as horn, with straight roots hollowed out to thin walls; these roots have curved prolongations that are filled with spongy marrow of exceeding lightness and is contained within a very hard, thin, convex skin, which is divided into two semi-cylinders, the convex side being placed over the concave side, so that after being curved both may be straightened out again by their elasticity, after the manner of a bow; so too, after being expanded they assume their curvature again, and thus strike the air with the greater force.

Most wonderfully, too, are shaped the hairy transverse feathery parts of the feathers which are of thin, most light, and yet strong structure, being elastic like a bow; and their hairy edges overlap so that they lie one over another, and thus hinder the passage of the air

which they strike, like the sails of Ships. And, so that the penetration of the air may be even better prevented, other smaller feathers are disposed over the interstices, and down over them like the scales of Fishes; so that the whole wing surface is like the roof of a house composed of many tiles, and by the aid of all its parts prevents even the slightest rift.

¶ *The order and manner wherein Birds move their wings during flight.*

THAT we may lay bare the mechanical process whereby flight is effected, we must examine precisely the particular parts of the wings that are moved when Birds are in flight, and the order and particular mode of their motion. When Birds in repose rest on the earth, their wings are folded up close against their flanks: but when wishing to start on their flight, they first bend their legs and leap into the air. Whereupon the joints of their wings are straightened out, to form a straight line at right angles to the lateral surface of the breast, so that the two wings, outstretched, are placed as it were like the arms of a cross to the body of the Bird. Next, since the wings with their feathers attached form almost a plane surface, they are raised slightly above the horizontal, and with a most quick impulse beat down, in a direction almost perpendicular to the wing-plane, upon the underlying air; and to so intense a beat the air, notwithstanding it be fluid, offers resistance, partly by reason of its natural inertia which seeks to retain it at rest, and partly because the particles of the

air, compressed by the swiftness of the stroke, resist this compression by their elasticity, just like the hard ground. Hence, the whole mass of the Bird rebounds, making a fresh leap through the air; whence it follows that flight is simply a motion composed of successive leaps accomplished through the air.

And I remark that a wing can easily beat the air in a direction almost perpendicular to its plane surface, although only a single one of the corners of the humerus bone is attached to the scapula, the whole extent of its base remaining free and loose, while the greater transverse feathers are joined to the lateral skin of the thorax. Nevertheless, the wing can easily revolve about its base like unto a fan.

Nor are there lacking tendon ligaments which restrain the feathers and prevent them from opening further, in the same fashion that sheets hold in the sails of Ships. No less admirable is Nature's cunning in unfolding and folding the wings upwards, for She folds them, not laterally, but by moving upwards edgewise the osseous parts wherein the roots of the feathers are inserted : for thus, without encountering the air's resistance, the upward motion of the wing-surface is made as with a sword; hence they can be uplifted with but small force. But thereafter, when the wings are twisted by being drawn transversely and by the resistance of the air, they are flattened as has been declared and will be made manifest hereafter.

¶ *A Bird's centre of gravity must be low.*

IT is known that the centre of gravity is the point in the centre of a body, wherefrom, if it be suspended, it will remain in equilibrium in every position; whereas, if it be suspended from any other point at a distance from the centre of gravity, then the body will not remain at rest save only in the single position wherein the straight line joining the point of suspension to the centre of gravity is perpendicular to the horizon. If there be taken the body A B C, which has its centre of gravity at D, and it be suspended from the point E, and it be

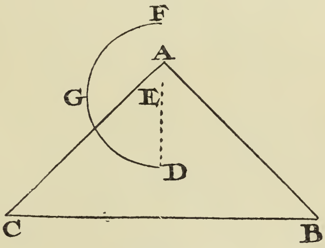


Fig. 2

possible to move it along the circumference of the circle F G D whose diameter F D is perpendicular to the horizon: it is indeed manifest that if the centre of gravity D be moved to any point G of the circumference of the circle, the body A B C, according to the law of the pendulum, will not remain at rest in that position, but will swing back to the lowest point D and remain there, for there alone is the line E D perpendicular to the horizon. Hence may be deduced conversely that, whenever the hanging body A B C, suspended from the

point E, remains at rest and if after being swung returns to the same position so that the lower face B C is level, necessarily the centre of gravity must be some point in the vertical line E D situated below the point of suspension E.

Here be it also remarked that, if a body immersed in a fluid return ever to the same position, its centre of gravity must lie in the lower portion, nearest the earth. If, therefore, the ball A B, immersed in water or in the air, always return to the same position in which B is the lowest point, it must follow that the centre of

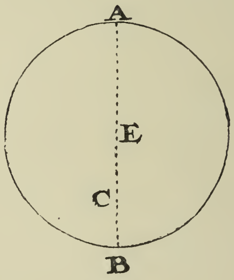


Fig. 3

gravity of the ball is situated in some point C, away from the centre, towards the point B, for this, too, follows from the law of the pendulum.

Therefore, since we see a Bird in flight always with its belly level—a position that it maintains without any effort—it follows that its centre of gravity is situated in the lower part of the breast and belly.

Next, since a Bird—in itself heavier than the air—is sustained by the force of its wings and falls not, and since its body is suspended from the points of attach-

ment of the wings in its upper part; therefore it is necessary that the centre of gravity should be below the roots of the wings in the lower part of the breast, and in a straight line perpendicular to the horizon and to the body of the Bird.

This statement is confirmed by the usual method whereby the centre of gravity of irregular bodies is ascertained. For if we place the body of a Bird plucked of its feathers, in various positions on the horizontal edge of a knife, we shall find that point where the Bird is balanced in equilibrium, that is the centre of gravity, in the straight line drawn from the articulations, or roots of the wings, to the middle-point of the pectoral bone, perpendicularly to the length of the Bird's body; in this precise position Birds rest when asleep on the twigs of trees.

We have seen already that the heavier parts of a Bird, which are the bigger, stronger bones and fleshy parts of the breast, are situated in the lower part of its body : for the bones of the legs and breast are large and strong. On the other hand, the backbone and ribs are thin and light. Similarly, the muscles of the breast, the thighs, and of the legs hanging below are equal or even superior in weight to the entrails and all the remaining muscles of the Bird together; so that the lower part of the breast should be by far the heavier, Nature placed the muscles that beat the wings, not in the upper shoulder-bone, but, as already noticed, in the middle of the pectoral muscle.

Opposed hereto, the upper thoracic cavity is filled with air, and is thereby lighter than the lower portion. The greater part of the abdominal cavity, also, is occu-

pied by air above the intestines, which lie over the abdominal muscles by reason of their weight. From this disposition of the various parts we clearly perceive that Nature carefully devised that the centre of gravity of Birds should lie below the roots of the wings, so that they might remain on level belly in flight. For thus the heavy mechanism of the Bird may be sustained and prevented from falling by the powerful beating of the wings on the air.

Several observations may be brought forward against the above theory. For we may observe that in standing and in walking a Bird balances itself about a point situated between the joints of the shoulder-blades and the hips, through which passes a line drawn perpendicularly to the horizon and falling between the claws resting on the earth. Wherefrom it may be inferred that the centre of gravity of a Bird falls behind the joints of the wings, towards the tail. Moreover, when standing, a Bird holds not its body quite horizontally, but balances it in a slightly inclined position.

Though these things be true, yet are they not at variance with the theory above laid down; for, although the centre of gravity can never lie anywhere but in the position indicated, nevertheless this position itself may vary according to the requirements of the animal. The neck of a Bird, for instance, is of considerable heaviness by reason of the large number of bony vertebræ and the weight of the head : hence, if the head is either drawn back, or extended forwards, thus increasing horizontally the length of the body or diminishing it, the balance will be altered and the centre of gravity of the Bird will be displaced either towards the head, or towards the tail.

Thus, we may observe that a Goose when flying stretches forward its neck like the arm of a balance with the weight of the head at its extremity; wherefore the centre of gravity of the whole mass is displaced towards the head. Further, a Bird in flight always folds up the joints of its legs, drawing them up to the breast, save only in the case of Geese and some other Birds whose heads are heavy, so that the weight of the legs may be displaced either forwards or rearwards according to the requirements of equilibrium. Thirdly, when a Bird is on the ground, its wings are folded back against its flanks, thereby augmenting the weight in the rear: but when it flies, it spreads out its wings, bending them towards its head; thus making heavier its foremost part. By these three causes the centre of gravity of a Bird may be moved forward through a considerable distance, until the line joining it to the articulations of the wings be exactly perpendicular to the horizon and to the length of the Bird's body; thus, in a prone position, a Bird may most easily by beating the air with its wings fly through the air in successive leaps.

Most clearly, too, is this theory confirmed by the answer to the question, Why a Bird when sleeping hides its head beneath its wing. The first and obvious reason is that it cannot during its sleep perform a voluntary and fatiguing action, hence it cannot support the weight of its neck and head; wherefore it must perforce rest them somewhere. But the second reason that concerns the matter is that by drawing back its head and resting it on the rear part of its body, just as if it shortened the arm of a balance, the Bird moves rearward its centre of gravity so that the latter is placed vertically above the

claws that firmly grasp the branch of the tree like a vice, as already stated; and thus the Bird may rest in equipoise. These observations have been set out first to give a clearer understanding of the mechanical work by which flight is effected.

¶ *The quantity of air acted upon by the wing of a Bird in flight is in shape a solid sector swept out by a radius equal to the span of the wing.*

LET there be a flying bird A C B G, the span of whose wing is equal to A I, and whose wing revolves when flapped about the centre A constituted by the joint of the humerus bone. Wherefore in its beat it moves through the sector A E P. But the wing A E is not

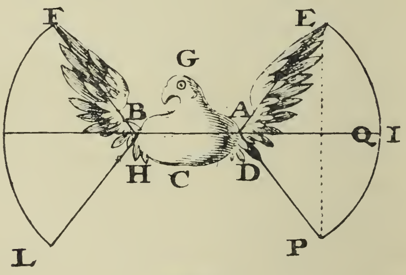


Fig. 4

simply a straight line, but a plane surface, and therefore in its motion it sweeps out a solid sector. In truth the wing strikes no air beyond that which is contained in the solid sector swept out by its motion.

¶ *Wherein is explained in what manner the air offers resistance to the stroke of the wings.*

THOUGH it be true indeed that the air may be set in motion and flow by any driving force, however weak, and hence appears to offer no resistance to motion; nevertheless experience teaches that it does resist the strong, swift beat of a wing, and with the greater force, the greater the swiftness of the beat. The causes of this resistance are evidently twofold. And firstly, since the air struck by the wing must of necessity be set in motion, whereas the surrounding air remains quiescent, as required by the nature of fluids; indeed, so that only a small portion of air be set in motion and displaced, it is necessary that it should be caused to rotate in a whirl within the great mass of quiescent air, as if in some enclosed vessel; and the particles of the round mass of air that is rotated will come into contact with and rub against the particles of the surrounding still air. But such friction and commotion cannot take place without the development of force and resistance; whence it follows that the stroke of the wing is opposed and resisted by the motion of the air.

Secondly, too, the air when struck offers resistance by its elastic virtue, through which the particles of the air compressed by the wing-beat strive to expand again. Through these two causes of resistance the downward beat of the wing is not only opposed, but even caused to recoil with a reflex movement; and these two causes of resistance ever increase the more the down-stroke of the wing is maintained and accelerated. On the other hand, the impulse of the wing is continuously diminished

and weakened by the growing resistance. Hereby the force of the wing and the resistance become balanced; so that, manifestly, the air is beaten by the wing with the same force as the resistance to the stroke.

¶ *If the velocity wherewith the wings of a Bird in flight are beaten is equal to the velocity wherewith the underlying air recoils to the beat of the wing, the Bird remains in the same place.* (Fig. 4.)

IF a Bird flying in the air beats its wing A E in the direction of P with the same velocity wherewith the air, struck by the wing, recoils in the same direction; then, I affirm, that the Bird A C B G will neither ascend nor fall. For the Bird would, if it were resting on the solid ground, rise from the ground to the extent that the wings E A, F B were beaten; but when the ground is not solid, but, being air, recoils with the same velocity wherewith it is struck, then the Bird will ascend through the beating of its wings in exactly the same measure as it is caused to fall by the recoil of the fluid air on which the wings rest; hence, relatively to the earth, it will remain at the same distance from the surface.

¶ *Again, if the velocity wherewith the wings are beaten is greater than the velocity wherewith the underlying air recoils to the beat, the Bird will ascend, and the rate of its ascent will be equal to the difference between the two velocities.*

IN the same figure, since we suppose that the wing A E is beaten with greater velocity than the underlying air

recoils to the beat, then the path described by the wing will be longer than that taken by the underlying air. But this is impossible, for the wing cannot be beaten in the air save by drawing along with itself the air that surrounds it. Hence the greater motion of the wing must be retarded and cut short by some mechanical device, in order that its motion may be the same as the shorter motion of the air. And this is effected most ingeniously by dragging upwards the centre A of the wing together with the Bird itself; whereby, although the tip E of the wing describes the greater path E P, nevertheless the actual path of travel, relatively to space, is diminished in the precise measure wherein the centre A of the wing, and with it the entire wing together with the Bird itself, is drawn back. Therefore the rate of ascent of the Bird is equal to the excess of the velocity of the wing-beat over the recoil of the air beneath.

¶ *The power of those muscles that beat the wings is greater by ten-thousand times than the weight of the Bird.*

ALREADY we have showed that the power required for a man to leap is almost three-thousand times greater than his own weight; but with Birds it can be demonstrated that the power necessary for making a leap is in greater proportion still to their weight. For their weight is triply suspended in like manner and the leverage of their longer legs increases in much greater measure than in the case of men the motive force, which again

is multiplied more than twenty times by the number of the muscles of the legs; and lastly the motive force will be increased by the violence and swiftness of the leap, so that it is greater by three-thousand times than the weight of the Bird which leaps.

These things being so, since flight is effected by successive leaps through the leverage of the wings, which are strongly flapped by the two pectoral muscles; and since the motive power exerted by muscles is for any animal, as has been shown, proportional to the size of the muscles; therefore, the number and length of the ligaments, no less than the fleshy bulk of the muscles that beat the wings being greater, stronger, and not less in extent than the flesh of all the muscles of the legs, it is manifest that the power employed by Nature to beat the wings is greater than that put forth in leaping from the ground. Next, I observe that the bulk and weight of the muscles of a man's legs are less in proportion to the bulk and weight of his entire body than is the case with a Bird; but the power of all muscles has always the same proportion to the resistance of the body they support, as the bulk or weight. Wherefore the power of the muscles in a man's legs only exceeds the weight of his body to a far smaller extent than the power of the wings of a Bird surpasses the weight of its body.

Moreover, I notice that the leaps through the air which are made during flight may be continued during four hours and more without intermission; nay, we may see Swallows on the wing throughout the day; but on the ground neither men nor four-footed beasts, no, nor

Birds with clipped wings, can continue to leap with the same vehemence for the space of half-an-hour or an hour. And muscular power, the longer it acts and remains capable of raising many times the same weight, must by so much be more abundant and efficient, as in the case where it is not able to perform the same task, or only for a shorter time. Therefore the power of the wing-muscles is greater far than the power of the leg-muscles; it is, in fact, more than four times as great. And this may be proved by this argument. If a man stand first on hard and firm ground, and next on a mattress of wool or sand, or any yielding surface; and if, bending his legs, he leaps with the same strength in each case, it is evident that the leap made from the hard ground will be the greater, while that made from soft and yielding ground will be the smaller. If, however, the leaps are to be equal in each case, that is to say if they are to reach to the same height, it is necessary that the man standing on yielding ground exert greater strength than the other one in the exact measure that the motion of recoil is diminished by the softness of the ground, for the recoil is the cause of the leap. And since the air, on which the wings of Birds are supported, is fluid and yielding, for this reason the action of flying, or of making leaps through the air, requires far greater power; in fact, four times as much as is required for a leap from the firm gound. But this power has been shown to be almost three-thousand times greater than the weight of the animal to be lifted. Hence the power that is exerted by the pectoral muscles during flight can be not less than ten-thousand times the weight of the bird.

¶ *Wherein are set forth the reasons for the immense power of the wings.*

SUCH excessive power of the pectoral muscles of Birds seems to arise, firstly, from their large size and from the more compact and stronger organic structure of the fibres of the pectoral muscles; for these fibres are thicker and closer, forming a dense and compact fleshy structure, whereas the muscles of the legs are formed of meagre, spare flesh. By reason hereof the former can be extended more forcefully and vehemently, so that the former are able to exert more power than the latter.

Secondly, the action of the wings is increased by the decrease in resistance, for the body of a Bird is disproportionately lighter than that of man or of any quadruped; that is, the weight of a Bird is in smaller proportion to the weight of the latter animals than its mass to theirs. This is evident since the bones of a Bird are porous, hollowed out to extreme thinness like the roots of the feathers, and the shoulder-bones, ribs, and wing-bones are of little substance; the breast and abdomen contain large cavities filled with air; while the feathers and the down are of exceeding lightness. Hence the power of the wings is increased in duplicate ratio : firstly, by the increase in the force of the muscles, and secondly by the decrease of the weight to be supported.

This downward pull is diminished the more as its downward movement is retarded by the spread of the wings and of the tail; hence the force of the wings can the more readily effect the leaps through the air, as the

resistance of the downward pull of the Bird itself is diminished.

Thirdly, in leaping from the earth the projectile momentum is immediately extinguished so soon as the feet come into contact with the earth again; whence it follows that the momentum must forthwith be renewed. On the contrary, when a Bird is flying through the air, the projectile force is not extinguished by the fluid air, wherefore it assists the succeeding leaps which are made by the beating of the wings.

Fourthly, in effecting separate leaps from the earth, the soles of the feet come into contact with the ground not without experiencing hurt and painful injury, whence arise fatigue and weakness. But no such hurt results from leaping through the air; wherefore, since the motive force is not weakened to the same extent, longer, more powerful, and more lasting leaps may be made through the air. The various causes set forth above render the process abundantly clear.

¶ *In what manner an oblique transverse force may propel straightly a body unaffected by the motion.*

IT is taught by the science of mechanics that the action of the wedge A B C, through which two parts E F G and L M N of the same body must be separated from one another, amounts to the forcing of the two resisting bodies D E and H M over the inclined surfaces C A and C B of the wedge, along which they seek to ascend when the wedge is driven in a direction from I to C. And the same transverse motion over the inclined faces C A and C B must take place when the two adjacent bodies

D F and H M are forced towards each other; for in this case the smooth wedge A B C seeks to escape in the opposite direction and to recoil from C to I, being expelled through the pressure of the collateral bodies, in the same manner as the smooth pips of a fruit may be projected to a long distance by being compressed be-

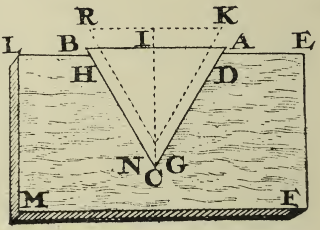


Fig. 5

tween one's fingers. And this propulsion is made with the same force and momentum as that wherewith the bodies D F and H M compress the inclined faces C A and C B : the expelling force having the same proportion to their absolute force as the heights A I, B I of the planes to the lengths A C, B C of their inclination.

¶ *If a Bird suspended in the air strike with its outspread wings the undisturbed air, with a motion perpendicular to the horizon, it will fly with a transverse movement parallel to the horizon.*

LET the Bird R S be suspended in the air with its wings B E A and B C F expanded and its belly downwards, and the under surfaces of the wings B E A and B C F strike against the wind perpendicularly to the

horizon with such force as to prevent the bird from falling, then I hold that it will be impelled horizontally from S towards R. And this happens because the two osseous rods (*virgae*) B C and B E by muscular strength and on account of their hardness are able to resist the pressure of the wind, and, moreover, to retain their shape, but the afterparts of any kind of wing yield to the air pressure, as the flexible feathers are able to move about the wing bones (*manubria*) or their boney axes B C and B E; and so it follows that the ends A

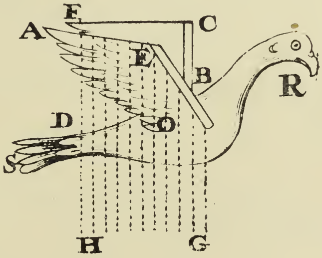


Fig. 6

and F of the feathers close in towards one another, by which means the wings assume the form of a wedge with its apex towards A F. But as the surfaces of the wedge are compressed on all sides by the ascending air, the wedge is of necessity squeezed and driven towards its base C B E. And as the said wedge formed by the wings cannot move forward without taking with it, since it is attached thereto, the body of the Bird R S, which is swimming in the air and can therefore be moved freely from its position, for this reason it is able to give room to the incoming air in the place of

the air driven out; and therefore the bird moves with a horizontal motion towards R.*

Let us now take the case of undisturbed opposing air which is struck by the flexible portions of the wings with a movement perpendicular to the horizon. Since the sails and flexible portions of the wings assume the shape of a wedge, with the apex towards the tail, when acted upon by the force and compression of the air, whether the wings strike the quiescent air beneath, or whether the air rushes up against the outstretched wings with their rigid wing-bones; in both cases the flexible feathers of each wing yield to the pressure and close in towards one another. Therefore, of necessity, as will be presently shown, the bird will be moved forwards towards R.

¶ *Wherein is explained the way in which the horizontal flight of Birds is effected.*

To have brought about flight, it is evident that Nature impelled birds upward and held them suspended in the air, and afterwards they were enabled by horizontal movements to be carried about. The first step could not have been accomplished except by successive leaps; next the heavy bird was carried up and its descent prevented by the beating of its wings, and then, as the downward pull of its weight is perpendicular to the horizon, beats with the flat face of its wings would be made by striking the air in the same perpendicular

* A somewhat obscure passage. The argument is re-stated in more explicit terms in the next paragraph.—EDS.

direction; and in this fashion has Nature brought about the suspension of the Birds in the air.

Concerning the second and transverse motion of Birds, some people do blunder strangely, for they think that it ought to be done as in Ships, which, by the exertion of a horizontal force towards the stern, through the means of oars, the while floating on the quiet and therefore resisting water beneath, recoil at the contrary motion, and so are moved forward. In the same way they affirm that the wings are flapped with a horizontal movement towards the tail and so strike against the undisturbed air, the resistance of which occasions, by the reflex action, their forward motion.

But this is repellent to the evidence of the senses and of reason, for we never see the larger Birds, such as Swans, Geese, and the like, while flying, to flap their wings towards the tail with a horizontal motion, but always to incline them downwards, describing circles set perpendicularly to the horizon. Moreover, in Ships, the horizontal motion of the oars can be easily accomplished and a perpendicular stroke upon the water would be useless and unnecessary, as there is no need to prevent their descent when they are sustained by the weight and density of the water. But in the case of Birds, it would be foolish to make such a horizontal motion, which would rather hinder flight as the speedy downfall of the heavy Bird would result from it; wherefore, the Bird must be sustained by continual vibrations of the wings perpendicularly to the horizon.

Wherefore Nature was compelled to use, with remarkable shrewdness, a movement which both sustained the Bird and propelled it horizontally. It ac-

complishes this by beating the air perpendicularly to the horizon, but with oblique strokes, which is rendered possible solely by the flexibility of the feathers; for in the act of striking the wing-fans acquire the shape of a wedge, so that of necessity the Bird is moved forward horizontally, as has been said.

¶ *The use of the tail of the Bird is to direct the course of flight upwards and downwards; but not to the right and left.*

THE opinion derived from the ancient Philosophers prevails that the tail in Birds performs the same function as the rudder in Ships; and because Ships, floating horizontally on the smooth surface of the water, can be turned by the effect of the helm only to the right and left, hence it is commonly believed that Birds direct their bodies to the right and left, when flying, by the movement of the tail.

Of a truth the falsity of this opinion can be easily proved not only by reason but by experience. Because, if the rudder of a Ship were adapted in the same way and placed in the same position as the tail in a Bird, that is to say, if the face of the rudder-blade with the changed axis were fixed to the stern, not perpendicularly to the horizon and to the surface of the water, but extended horizontally, so that in the water it could be inclined upwards and downwards to the surface thereof, then indeed were one able to see that the Ship could in no wise be turned to the right nor to the left by such alteration of its rudder.

Moreover, we see that Pigeons, Swallows, and

Hawks, when they direct their course horizontally to the right or to the left, do not spread their tail, nor do they bend it up nor yet down, but hold it straight. Finally, Pigeons with their tails cut, or Bats that possess no tails at all, easily turn in the air and make horizontal curves in their flight. And these examples must in sufficient measure confute the common error.

But I will not deny that the tail in Birds truly may perform the use and function of a rudder; but I affirm that it serves to direct the course in flight upwards and downwards. And this I prove as follows:

Let there be a Bird A B with its centre of gravity at C; now this Bird while flying directly and horizontally

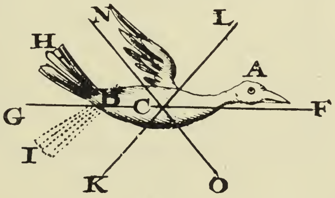


Fig. 7

from G to F inclines downwards the surface of its long tail B H. For, while the Bird moves from G to F, through quiet and still air, its body surface A B is able to glide forwards freely and without impediment. Not so its rear part, the upheld surface of which is not straight and level, on account of the elevation of the big and very long tail B H, which strikes against the still air; and by this means such striking of the air tends to remove the aforesaid obstacle, as it would stretch the tail out straight if it were not held in its curved position by muscular force. Wherefore it fol-

lows that, as the whole body of the Bird is turned about its centre of gravity C on which it is poised, it must assume the position L K, and its head must be moved up from A to L.

In the same way, if the tail be depressed as in B I, when the Bird is flying from G towards F, it strikes the quiet air beneath, and in this way the tail is raised from B towards N around the same centre of gravity C and therefore the head A is lowered towards O. A mechanical demonstration proves this, which can also be confirmed by experiment.

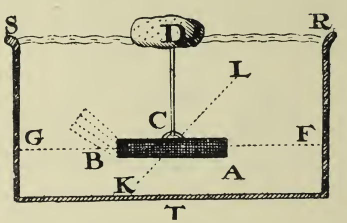


Fig. 8

In the vessel R S T, full of water, an oblong strip of iron A B is sunk, which is suspended from its centre of gravity C by a thread tied to the cork D, so that the immersed strip can be moved horizontally, and a small strip B H is attached to its rear edge like a Bird's tail. If this small strip be bent upwards and the body A B be drawn by the thread C D horizontally towards F, the leading end A is turned by the swift motion towards L about its centre of gravity C, nor does it ever revolve horizontally to the right or to the left; wherefore this should also hold good of Birds flying through the air.

¶ *How and by what means Birds, when flying, alter their course to the right or to the left.*

Experience and reason show that a small rudder moved to the left may slowly turn a big Ship in the same direction when the Ship is travelling on a straight course through the water; but while the Ship is at rest, that is to say, if it is not propelled by the wind or by oars, then the rudder will effect no turn at all in the Ship's course. In the other case, where there is no rudder, if the oars on the right side are pulled so as to drive the water towards the stern, whether the Ship be still or whether under way, the bows are always speedily turned towards the left side.

This also happens, if the oars on the right side drive the water backwards more swiftly than those on the left. The reason for this does not warrant explanation, since it is self-evident; therefore, in the same way, while a Bird is floating in the air, poised on its centre of gravity, if the right wing alone is bent obliquely downwards, driving the air towards its tail, its right side of necessity—as in a Ship, as will be seen—will be moved gently and slowly to the left side. From which it follows that the fore part of the Bird, moving round its centre of gravity, is turned towards the left side.

We ourselves in truth experience this, while swimming; for by bending the right arm, with the hand stretched towards the rear, we turn horizontally to the left. We have observed this in Pigeons flying; for whenever they wish to turn towards the left side they raise their right wing and flap it strongly, driving the

air with an oblique motion towards the tail; from which it follows that the shoulder and whole right side of the Bird are raised above the horizontal plane, whereas the left side is depressed because the Bird's weight is not equally sustained by the uneven flapping. By this means the turn and deviation of a Bird moving horizontally are very quickly made. Finally, I am of opinion that the turn cannot be effected by a lateral movement of the Bird's tail in the same way as a rudder, because the tail can never be set perpendicularly to the horizon, but only obliquely.

And such obliqueness goes for nothing if the tail feathers are spread in the same direction as the rest of the body or from its axis like a waving flag; but it is necessary that the tail be bent both away from the direction of the Bird's axis and from its direction of motion in the horizontal plane. In this way, at best, the tail can only be obliquely inclined between the vertical and the horizontal. And because we see in Pigeons flying that such inclination of the tail feathers from the horizontal is very small, therefore they should go up or down more often than to one side; but this is not borne out by experience, for we see that in the same horizontal plane Birds turn with great quickness.

I do affirm, therefore, that birds do not spread the tail when turning sideways, but when going up or down, and most of all when they are slackening the speed they have gathered, so as to land without shock or hurt.

At the same time the argument is advanced that it can be sufficiently well done (*i.e.*, the turn with tail), though with difficulty.

¶ *If the body of the Bird A C be moved at an acquired speed through the air in a longitudinal direction from C towards A, and if while flying it bend its outstretched neck with its head B A towards the left side B I, the course of the entire Bird is deflected towards B I.*

LET D be the centre of gravity of the body of the bird B C, and let E be the centre of gravity of the head and long neck A B, and when the neck is bent to B I let the centre of gravity be at F; join D F.

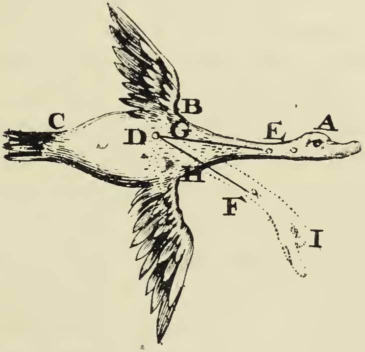


Fig. 9

Now as the weight C B is to B A, or to B I, so is the distance E G to G D; therefore F H is equal to H D.

It is plain that before the neck is bent the centre of gravity of the whole Bird will be in G, and that from the acquired speed it would be carried from D towards E. But as the neck is bent, the same centre of gravity G is turned from this direct course and it moves from G towards H, but retains the same initial impetus from

the tail towards the head. Therefore from these two forces a transverse motion is set up in the direction D I, which course is subsequently followed by the Bird.

¶ *It does not appear possible that Birds, flying horizontally, can depart quickly from their course by the transverse flexion of their head and neck.*

LET us consider the two ways by which a Ship, moving through the water, is able to turn to the right and to the left. Firstly, if the oars on one side impel the water more strongly towards the stern than the oars on the other side. Secondly, if, while the ship is moving, the rudder, either in the stern or in the prow, is turned laterally, perpendicularly to the horizon. These two operations largely differ from one another; for the turning of the Ship is effected, on the one hand, by a considerable exertion of motive force on the part of the rowers, and on the other by the inappreciable power of the Steersman grasping the tiller, who, though directing the movement, does not effect it by his own strength, but from the impetus acquired by the Ship and from the rudder resisting the impact of the water; moreover, the turning movement made by the oars on one side is performed very quickly, but very slowly by the rudder.

From these facts we can judge, in the similar action of Birds flying, whether the bending of the neck can not fulfil the function of a rudder.

Firstly, if the neck inclined laterally had the strength of a rudder and thereby the Bird were able to alter its course to the right and left, therefore, in the same way,

by raising or lowering its neck, a Bird in flight were able to direct its course upwards or downwards.

But, as it cannot be said that the large tail, which, acting as a rudder, so evidently produces the up and down movements, was made by Nature for no reason, it must be confessed that the bending of the neck does not fulfil the function of a rudder.

Secondly, Eagles, Hawks, and Swallows have a very short neck and a small head of but little weight; therefore, the centre of gravity could only deviate a very small way from the direction of the axis of the Bird and for this reason it would only turn with much difficulty and very slowly in a lateral direction; but so false is this, that in truth they whirl round almost in the twinkling of an eye; while, on the other hand, Geese, Ducks, and Swans and other Birds of this kind, possessed of a long neck and a very heavy head and beak, turn most slowly when they are flying. It must therefore be confessed that bending the head and neck laterally in no wise produces a horizontal turning movement.

Thirdly, if the centre of gravity of the entire Bird should depart considerably from its axis by a lateral bending of the neck, the Bird could not maintain its horizontal equilibrium, and therefore the side depressed would have to be righted by a violent exertion of the wing on that side. From which it would follow that a contrary action to the first would be made in the interests of gravity, which would interfere with the turning movement; and such an action would be vain and useless; moreover being foolish and sorely at variance with Nature's shrewdness.

Nor may you say that the speediest turns of Birds

are made by the strong flapping of one wing towards the tail, and that slow turns can be made by bending the neck sideways without any special effort by the wing, in the same way as Ships are put about by means of a rudder and without using the oars, for I am of opinion that the slow circling of a bird is accomplished not by a stronger movement of one wing that either of them exert in straight flight; for it is sufficient that the wing, to make the turn, should incline for a little while towards the tail and strike the air there, so that without any fresh exertion the slow lateral turn of the bird may be accomplished in the quickest way.

¶ *How Birds, without flapping their wings, can sometimes rise in the air for a short time not only horizontally, but also obliquely upward.*

IT is clear from what has been said that the projectile force is communicated to a Bird's body by the flapping of the wings in the same way as motion is given to a Ship by the strokes of the oars, which motion is of a constant nature.

Suppose, however, that the action of the oars stops, nevertheless the Ship proceeds upon its way until its movement is arrested by external forces.

Therefore both Bird and Ship from the motion imparted to them have the same properties as an arrow and other projectiles; and just as in a Ship in motion, if its axis is deflected from a straight course by the strength of the helm, then this same motion comes into play on the altered course, and the voyage is continued; so also in the Bird A, moving horizontally along the

straight line A B C, as often as its axis is directed upward through B D by the force of its tail acting as a helm, of necessity its impetus follows an upward movement through the parabolical curve B E F, but it is true that such ascent stops suddenly, the natural gravity of a Bird producing this effect and tending to bring it down. While the force of gravity is less than the velocity, the Bird rises upwards through B E, and when at F the forces equalise, the Bird is seen to float at that point for a little while, moving with expanded wings,

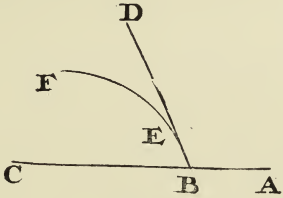


Fig. 10

almost in the same plane parallel to the horizon; for a bird cannot remain entirely motionless at the same point in the air, therefore upward flight cannot be made exactly perpendicularly to the horizon, but always obliquely through the line of a parabola, as projectiles move.

Therefore, after this rise is made, either the bird continues in a horizontal course for a short time because the equalisation of the forces soon ceases, or as the projectile force is spent it descends at a constantly increasing speed until brought up by external forces. Hence the necessity arises for renewing the impulse through the air by fresh strokes of the wings.

I note also that the two forces aforesaid, projectile and natural gravity, sometimes mutually retard and destroy each other, as happens in ascent; and sometimes add to one another so that a very high velocity results from their combination, thus Hawks fall down like arrows to strike little Birds and tear them with their claws.

There are, indeed, some who imagine that Birds hover in the high regions of the air with less difficulty than when near the earth, because they think they weigh less there on account of being less attracted by the earth's magnetic force, which is the cause of gravity according to their ideas; for just as iron when far away from a magnet does not feel its power nor is attracted by it, so they think Birds when high up escape from the force of gravity. And they imagine that this is why Eagles, flying high, are seen, as it were, at rest in the air with their wings spread and motionless for long periods, whilst near the earth when beginning to fly they are compelled to beat the air with quick recurring strokes.

But such ideas appear invalid. Firstly, on account of the difficulty of the hypothesis, as we explain elsewhere; secondly, because Hawks, when near the ground where the magnetic force is supposed to have the greatest effect, after they have acquired an impetus, do not flap continually, but with the same infrequence as when high up, and nevertheless they fly quite easily. Therefore they are able to hover without continual flaps in the highest aerial regions, not on account of the decreased magnetic virtue of the earth, but by strength and acquired momentum.

Thirdly, the high regions of the air are never quite still, but are always agitated by the wind as the movements of the clouds show; so the Bird with outspread wings is carried up by the wind, or at any rate the spread wings allow it to come down very slowly. In the air, the descending force of gravity is retarded by the wide surface opposed, in the same way as a strip of very thin iron sinks very slowly through water if care is taken that it does not fall edgewise. Hence it is inferred what the most potent causes of the easy flying of a Bird, in the high air, can be.

¶ *How the flying impetus acquired by a Bird is checked on landing.*

BECAUSE of the law of Nature that hard bodies in motion cannot come into contact with another hard and stationary body without a shock which causes their parts to break and shiver; it is necessary to insure that Birds at the end of a flight should come to ground without dislocating or breaking their legs, wherefore the severe shock, which bodies in motion incur, must be avoided.

But this cannot be done unless the Bird's impetus is gradually checked and stopped before it comes in contact with the earth, for, when impetus is lost, a gentle landing can be made.

Now the ways and means by which the speed is slackened at the end of a flight are these. The Bird spreads its wings and tail so that their concave surfaces are perpendicular to the direction of motion; in this way, the spreading feathers, like a Ship's sails,

strike against the still air, check the speed, and so that most of the impetus may be stopped, the wings are flapped quickly and strongly forward, inducing a contrary motion so that the bird absolutely or very nearly stops.

Any remaining impetus is absorbed by its extended feet, so that it takes the ground not heavily, but gradually, with bent joints yielding to the impact and with slowly relaxing muscles.

¶ *It is impossible that men should be able to fly craftily by their own strength.*

THREE principal points ought to be considered in flying: firstly, the motive power by which the body of the Animal may be sustained through the air; secondly, the suitable instruments, which are wings; thirdly, the resistance of the Animal's heavy body.

The degree of motive power is known by the strength and quantity of the muscles, which are designed to bend the arms or to flap the wings. And because the motive force in Birds' wings is apparently ten-thousand times greater than the resistance of their weight, and as Nature has endowed Birds with so great an excess of motive power, the Bird largely increases the strength of its pectoral muscles and skilfully decreases the weight of its body, as we have hinted above.

When, therefore, it is asked whether men may be able to fly by their own strength, it must be seen whether the motive power of the pectoral muscles (the strength of which is indicated and measured by their size), is proportionately great, as it is evident that it must ex-

ceed the resistance of the weight of the whole human body ten-thousand times, together with the weight of enormous wings which should be attached to the arms. And it is clear that the motive power of the pectoral muscles in men is much less than is necessary for flight, for in Birds the bulk and weight of the muscles for flapping the wings are not less than a sixth part of the entire weight of the body. Therefore, it would be necessary that the pectoral muscles of a man should weigh more than a sixth part of the entire weight of his body; so also the arms, by flapping with the wings attached, should be able to exert a power ten-thousand times greater than the weight of the human body itself. But they are far below such excess, for the aforesaid pectoral muscles do not equal a hundredth part of the entire weight of a man. Wherefore either the strength of the muscles ought to be increased or the weight of the human body must be decreased, so that the same proportion obtains in it as exists in Birds.

Hence it is deduced, that the Icarian invention is entirely mythical because impossible; for it is not possible either to increase a man's pectoral muscles or to diminish the weight of the human body; and whatever apparatus is used, although it is possible to increase the momentum, the velocity or the power employed can never equal the resistance; and therefore wing flapping by the contraction of muscles cannot give out enough power to carry up the heavy body of a man.

There only remains the diminution of the weight of the human body, not in itself, for this is impossible, its mechanism must remain intact, but especially and respectively to the aerial fluid in the same way as a

strip of lead can float on water if a certain amount of cork be attached to it which causes the entire mass of lead and cork to float, being of like weight to the amount of water which it displaces, according to the law of Archimedes. And this device Nature uses in fishes. She places in their bellies a sack full of air by means of which they are able to maintain their equilibrium, so that they can remain in the same place as if they were part of the water itself.

By this same device some have lately persuaded themselves that the weight of the human body is able to be brought into equilibrium with the air, that is to say by the use of a large vessel, either a vacuum or very nearly so, of so great a size that it is possible to sustain a human body in the air together with the vessel.*

But we easily perceive this to be a vain hope as it is necessary to construct the vessel of some hard metal such as brass or copper, and squeeze out and take away all the air from its interior, and it must also be of so great a size that when in the air it displaces a quantity of air of the same weight as itself, together with the man fastened to it; wherefore it would have to occupy a space of more than 22,000 cubic feet; moreover, the plates composing the sphere must be reduced to an extraordinary thinness. Furthermore, so thin a vessel of this size could not be constructed, or, if constructed, preserved intact, nor could it be exhausted by any pump, much less by mercury, of which so large a

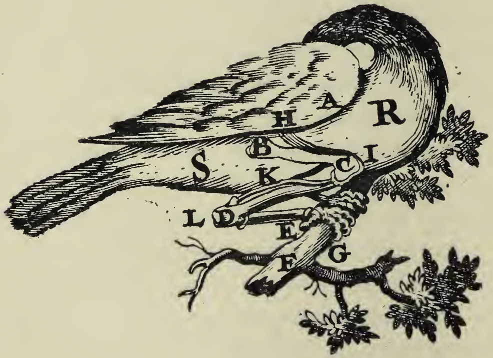
* The reference is to the writings of Francesco Lana and his imitators, Sturm and others.—*Vide* "Aeronautical Classics," No. 4.—EDS.

quantity is not to be found in the world, nor could be extracted from the earth, and if such a great vacuum were made the thin brass vessel could not resist the strong pressure of the air, which would break or crush it. I pass over the fact that so great a machine of the same weight as the air would not be able to keep itself in exact equilibrium with the air, and therefore would incontinently rise to the highest confines of the air like clouds, or would fall to the ground.

Again, such a large mass could not be moved in flight on account of the resistance of the air; in the same way feathers and soap bubbles can be moved only with difficulty through the air, even when they are blown by a light breeze, just as clouds, poised in the air, are driven by the wind.

At this point we cease to wonder that Nature, who is accustomed everywhere to imitate others' advantages, makes the swimming of fishes in water so easy and the flying of Birds through the air so difficult, for we see whereas fishes can remain in the midst of water, being of their own accord and without effort held up and poised, and can very easily descend and ascend, and are only moved by the strength of muscles placed transversely and obliquely to the direction of motion; on the other hand, Birds are not able to float in the air but owe their sustentation to the continual exertion of strength and a projectile force, not external, but natural and intrinsic, by contracting their pectoral muscles by which they make a series of bounds through the air; and this requires enormous strength, as they are not going upon feet supported on solid ground, but on wings supported by very fluid and greatly agitated air.

Nevertheless, I say that the act of flying is not difficult; indeed it is very simple and very easy in the various possible ways by which it can be accomplished. And the reason why flying is not performed in the same way as swimming is that Nature does not work miracles; fishes can easily float in heavy water, but it is impossible that Birds, made of bones, flesh, and blood two-thousand times heavier than the air, can float in the air.



See page 9.